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U.S. Department of the Interior
Minerals Management Service
Pacific OCS Region

THE EFFECTS OF AN OIL SPILL AND FREEZE EVENT ON INTERTIDAL COMMUNITY STRUCTURE IN WASHINGTON

FINAL REPORT

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SUMMARY

On Dec. 23, 1988, roughly 231,000 gallons of fuel oil were spilled offshore near Grays Harbor, Washington. Oil came ashore under stormy conditions, primarily contacting high intertidal zones and fouling logs and drift algae high on beaches. The impacts of this oil were studied at previously established intertidal sites along the coast, and at new sites that received particularly heavy oiling. A second major event in the form of a hard freeze struck this shoreline 6 weeks after the spill. The responses of plants and animals to these two events were studied at rocky (exposed and protected), cobble, and sand beaches along the coast, primarily by comparing communities in "oiled" and "unoiled" areas. Nine rocky, 6 cobble, and 6 sandy sites were studied; each was sampled during at least one winter and at least two summers. Wherever possible, permanent transects were established for long-term study of biotic changes.

Descriptions of zonation and species composition, and complete species lists for each habitat type are given. Site to site variation for all habitat types was high, despite attempts to choose sites that were similar in all physical respects except oil impact. In rocky sites, small differences in wave exposure, slope, and degree of sand impact clearly contributed to site variation. Some predictable seasonal changes were observed, with a number of plants and animals at all tidal levels declining in abundance in the winter. The freeze significantly reduced populations of mussels and of a number of algae at most sites, especially at the higher intertidal levels (which are exposed to the air for longer periods). In cobble areas, variation in species corresponded with substratum stability (rock vs. cobble vs. unconsolidated sediment), presence of standing water, and wave exposure. Seasonal changes were not quantified, and no freeze impacts were evident. In sandy areas, grain size (proportions of pebbles, coarse sand, and fine sand) clearly affected infaunal diversity and abundance. While these habitats have no macroalgae and are of generally low diversity, abundances of a few species can be very high in given zones. High temporal variation obscured seasonal patterns, but many species seemed to be less abundant in the winter, probably washed out by winter storms.

Oil effects at all habitat types were very difficult to distinguish from freeze effects and from natural site-to-site variation. Possible negative impacts of oil at rocky sites were seen for a few algal and animal species, especially in the high intertidal zone, although in each case we judge it more likely that these were freeze- or site-differences. In the cobble transects, the only impact that could unambiguously be ascribed to oil was on an oiled boulder, where some encrusting algae were killed. Large site-to-site differences, along with great organismal patchiness (many species were common at only one site or one quadrat) obscured any other possible oil effects -- but none were implicated. In the sand transects, the relative paucity of various amphipods at the heavily oiled Ocean Shores site, especially in high zones, could have been due to oil. No "recovery" of these populations was seen during the course of this study, however, suggesting that other factors intrinsic to this site may have been responsible.

Important parameters thought to contribute to community structure of each habitat type are discussed. Physical factors such as wave exposure, sediment movement, and time of exposure to the air are critical to the distribution and abundance of organisms in all habitat types. Biological processes include predation, herbivory, competition for space and light, and bioturbation.

In summary, due to a fortunate set of circumstances, the Nestucca oil spill appeared to cause relatively little damage to intertidal communities (rock, cobble, or sand) along the coast of Washington. It is clear that this oil, given its heavy, sticky nature and high potential persistence, could have had severe impacts on the productive, diverse plant and animal assemblages along this pristine shore as have spills on other rocky coastlines (see section 1.3); only the serendipitous combination of high tide, wind, and waves caused the oil to contact the shore in the zone where it could do minimal damage to intertidal communities, i.e. the supratidal zone. Long-term studies of the communities in these diverse habitat types are recommended to improve our understanding of seasonal and year-to-year variation, and thus to improve our ability to quantify man-induced changes when they occur.

ACKNOWLEDGMENTS

This report summarizes labor and assistance by many persons besides the author. The Summer 1988 sampling which provided the baseline for the research was initiated and funded by Olympic National Park (National Park Service), which continued to provide logistic support throughout the current project. I especially thank John Aho, Bruce Moorhead, Janice Walker, and all the coast rangers, particularly those at Mora. My invaluable field assistants were Michelle Woodbury, Sarah Cohen, Amy Sewell, and Liz Graham, plus a large number of volunteers. Ms. Sewell and Ms. Graham also contribute to the data analysis, graphics, and writing. Space while not in the field was provided by Dr. A.O.D. Willows and the Friday Harbor Laboratories, University of Washington. Grant management at the University was provided by Mr. Jerry Robichaud and the Institute for Environmental Studies. To all I am grateful.

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1.0 INTRODUCTION

1.1 Background

On December 23, 1988, the barge Nestucca was struck by its tug during a storm near Grays Harbor, Washington, leading to a spill of approximately 231,000 gallons of Bunker C fuel oil. This oil was carried ashore by wind and waves, eventually contacting over 150 miles of coastline between Grays Harbor and the north end of Vancouver Island. Much of the Washington coastline was hit within 24 hours (C. Janda, National Park Service, pers. comm.), allowing little time for weathering, although other areas were hit by oil that had been at sea for 1-2 weeks and had weathered (Strand et al. 1990). Oil contact was very patchy, with thick slicks found at some sites and virtually none at others. Extensive cleanup efforts, mostly involving mechanical removal of oiled sand and debris, were undertaken and generally were successful. Studies of the impact of this oil spill on birds and on intertidal and subtidal organisms were begun immediately, although intensive work on benthic habitats was not started until the following June.

Some baseline data for intertidal habitats were available from work done the previous summer (Dethier 1988) in Olympic National Park, which encompasses much of the impacted coastline within Washington. Many of the sites from this survey were examined immediately after the spill (within two weeks). Six weeks after the spill there was a natural disaster in the form of a hard freeze; unusually low temperatures and strong arctic winds combined with a low tide series and significantly affected intertidal plants and animals.

1.2 Purpose and Scope

The research reported here was designed to quantify oil spill damage to intertidal habitats along the affected portions of the coast of Washington. General techniques for damage assessment involved comparing communities of plants and animals from oiled versus unoiled areas, and (where possible) comparing pre-oil versus post-oil data from a given site. In the process of this study, detailed ecological descriptions for each habitat type were obtained, including data on distribution and abundance of over 300 species in rocky, cobbly, and sandy habitats. This report summarizes 1) The community structure of each of these habitat types, including some data on seasonal and year-to-year variation; 2) The impact of the oil spill on each habitat type; and 3) A general discussion of the processes affecting ecological patterns in each habitat type, insofar as these could be determined from static sampling. The report also includes a brief summary of oil spill damage assessment from other temperate coastlines, and a discussion of the impact of the February 1989 freeze.

1.3 Brief Review of Oil Impacts on Marine Organisms

There is a large and burgeoning literature on the impact of oil spills on marine organisms and environments. Reviews can be found in: Carthy and Arthur (1968), Nelson-Smith (1972), Boesch et al. (1974), Malin (1977), Wolfe (1977), Clark (1982), Jordan and Payne (1980), NAS (1985), Foster et al. (1988) and Strickland and Chassan (1989). This literature is a mix of largely anecdotal field observations of the impacts of actual spills, and laboratory studies of the impacts of oil fractions on the survival, behavior, growth, and physiology of various marine organisms (mostly invertebrates and fishes). Consensus from both types of studies is generally lacking.

Field studies, which usually are hampered in their rigor by the lack of pre-spill data for oiled and "control" areas, emphasize that all spills are different in their impact on natural habitats. Reaction of local communities varies with the type and amount of oil spilled, the type of substrates encountered, the wave energy during and after the spill, the cleanup methods used, the length of exposure of the organisms to the oil, and the types and life history stages of the organisms present (Straughan 1972, Gundlach and Hayes 1978, BNCOR 1980, Owens and Robilliard 1981). Field studies repeatedly have emphasized the need for a community approach to oil spill studies, i.e. studying the changes in species composition, distribution, productivity, and stability -- but there are virtually no data of this type available. The literature is full of generalizations based on a few studies, which are often contradictory; e.g., some researchers claim that intertidal organisms are hardy since they are already adapted to fluctuating conditions, and thus should be fairly resistant to oil damage (e.g., Sanborn 1977), while others claim that these organisms are already "on the edge" of their tolerances, and thus are highly sensitive (e.g., Clark and Finley 1977). While more data should be gleaned from the numerous studies done in the aftermath of the Exxon Valdez spill, these studies also suffer from a lack of baseline data, and their results are still tied up in litigation. It is clear that oil on shorelines can cause both extensive direct mortality of plants and animals and long-term, sublethal effects, and can inhibit recovery of ecosystems by affecting recruitment of larval and spore stages (reviewed in Foster et al. 1988). Although comparative data are limited, cleanup techniques often appear to increase ecological damage, especially when chemical dispersants are used (Foster et al. 1988, 1990).

Data from laboratory studies (reviewed by BEAK 1975, Neff and Anderson 1981, Anderson et al. 1987, Leschine et al. 1990) are clearer in that they are gathered under controlled conditions and with specified parameters, but many authors question to what degree sensitivities determined in the lab can be applied to organisms in nature. Certain trends are clear: larval and juvenile stages of most organisms (vertebrates and invertebrates) are more sensitive to oil toxicity than are adults; small crustaceans such as amphipods, isopods, and juvenile decapods tend to suffer high mortalities from oil exposure, while large decapods may suffer sublethal effects such as interference with molting; molluscs tend to get narcotized by oil, leading to reduced burrowing in bivalves, loss of attachment in gastropods, and other sublethal but hazardous effects; bivalves often concentrate oil fractions through their filter feeding activities, and thus either are killed outright (often seen in the field), or suffer long-term sublethal effects on growth and reproduction; meiofauna (and other organisms with high surface to volume ratios) are usually killed outright; most echinoderms are highly sensitive; polychaete worms vary greatly in their sensitivity; the chemosensory abilities of most invertebrates are damaged or destroyed by water-soluble oil fractions. The effects of oil on fishes appear to be less well studied, although eggs and juvenile stages are again known to be much more susceptible to oil than are adults. The effects of oil on algae, vascular marine plants, marsh grasses, and mangroves have seldom been studied in the lab, although field studies show that these, too, can be killed either by toxic fractions or by direct smothering by the heavier fractions of oil (see reviews, above).

Based on such field and laboratory studies and on knowledge of the chemical components, Leschine et al. (1990) have ranked various hydrocarbons for their potential harm to marine organisms and habitats. They give residual fuel oils (such as the Bunker C discussed here) a rating of 12/100 points for acute toxicity (low relative to other hydrocarbons), but 93/100 points for mechanical toxicity due to its heavy, sticky nature, and 100/100 points for persistence in the marine realm (making it the most persistent in natural habitats of the oils considered).

There is broader consensus on oil residence times in different habitat types, which of course will affect the ability of an ecosystem to recover from a spill (data in Gundlach and Hayes 1978, Jordan and Payne 1980, Vanderhorst et al. 1980, Blackman and Law 1981, Southward 1982, reviewed in Leschine et al. 1990). Wave-exposed rocky shores and high-energy sand beaches generally show removal of oil within weeks or months; exceptions are oil buried deep into the sand during a storm, or thrown up high onto sand or rock and thus out of the reach of the weathering abilities of waves. Under certain conditions, oil on rock (or even on sediments) can become asphalt-like, and weather only extremely slowly. Oil retention on protected rocky shores is much longer, so that impacts may be felt for years. Oil which becomes entrained in soft sediments in quiet bays, such as in mud flats or under cobbles on mixed-substrate beaches, may be retained for years or even decades. Oil in subtidal sediments is similarly long-lived (e.g., Sanders et al. 1980).

Estimates of "recovery time" are controversial because of the difficulty of defining complete recovery. Rocky shores may be rapidly recolonized by algae, and muddy sediments by worms, leading to high-biomass assemblages, but these usually bear no resemblence to the original flora and fauna of these habitats. Diversity may remain low for years, and "stability" of the community is even harder to establish. If critical (e.g. "keystone") predators are killed and are slow to recolonize, the community is not going to function in a normal fashion, and trophic dynamics will remain altered. Rough estimates (backed by little data) are for recovery time of high-energy sand beaches on the order of months to a few years, and of low-energy mud flats on the order of years to decades. Estimates for rocky shores vary from years to decades, again depending on definitions of recovery. Since many rocky shores are inhabited by hundreds of species, many of which are uncommon, slow-growing, and/or disperse very poorly, the estimate of decades of recovery time following extensive oil-induced damage does not seem unreasonable.

2.0 METHODS OF THIS STUDY

2.1 METHODS: General

The oil-impacted western coastline of the Olympic Peninsula of Washington contains no natural protected embayments except for the two large estuaries of Grays Harbor and Willapa Bay (Fig. 1A), neither of which received substantial oil except for the very mouth of Grays Harbor. Yet the range of substrate sizes (from mud to boulders) and beach slopes, the presence of rivers entering the ocean, and the protection provided by scattered sea stacks create a diverse set of habitats, each containing a different set of plants and animals and affected by different processes. As a result, the shoreline as a whole is extremely diverse and cannot be described as one habitat type (e.g., exposed rocky coast).

The different habitat types examined demanded the use of different methods for quantifying the distributions and abundances of plants and animals. However, all rocky shores were sampled in the same fashion, as were all sand beaches, etc. In all habitat types, transects with replicate quadrats or cores per level (tidal height) were run perpendicularly to the shoreline, from the high to the low intertidal zone. Wherever possible, we worked from near the low water mark up to zones where marine organisms disappeared. Different methods had to be used for counting patchy, large organisms such as starfish and tube worms. For each habitat type, we attempted to survey at least 2 oiled and 2 unoiled areas, and to keep all physical variables as similar as possible between sites. At the same time, we tried to survey sites along much of the affected coastline. Many of the sites were chosen pre-spill for a baseline study in Olympic National Park, and provide the only pre-spill data. The sites chosen, degree of oiling, number of transects, and other physical variables are listed in Table 1.

In order to examine seasonal variation, each site was sampled during at least one winter and at least two summers. The logistic difficulties of winter sampling did not allow greater sampling frequency. Only dominant

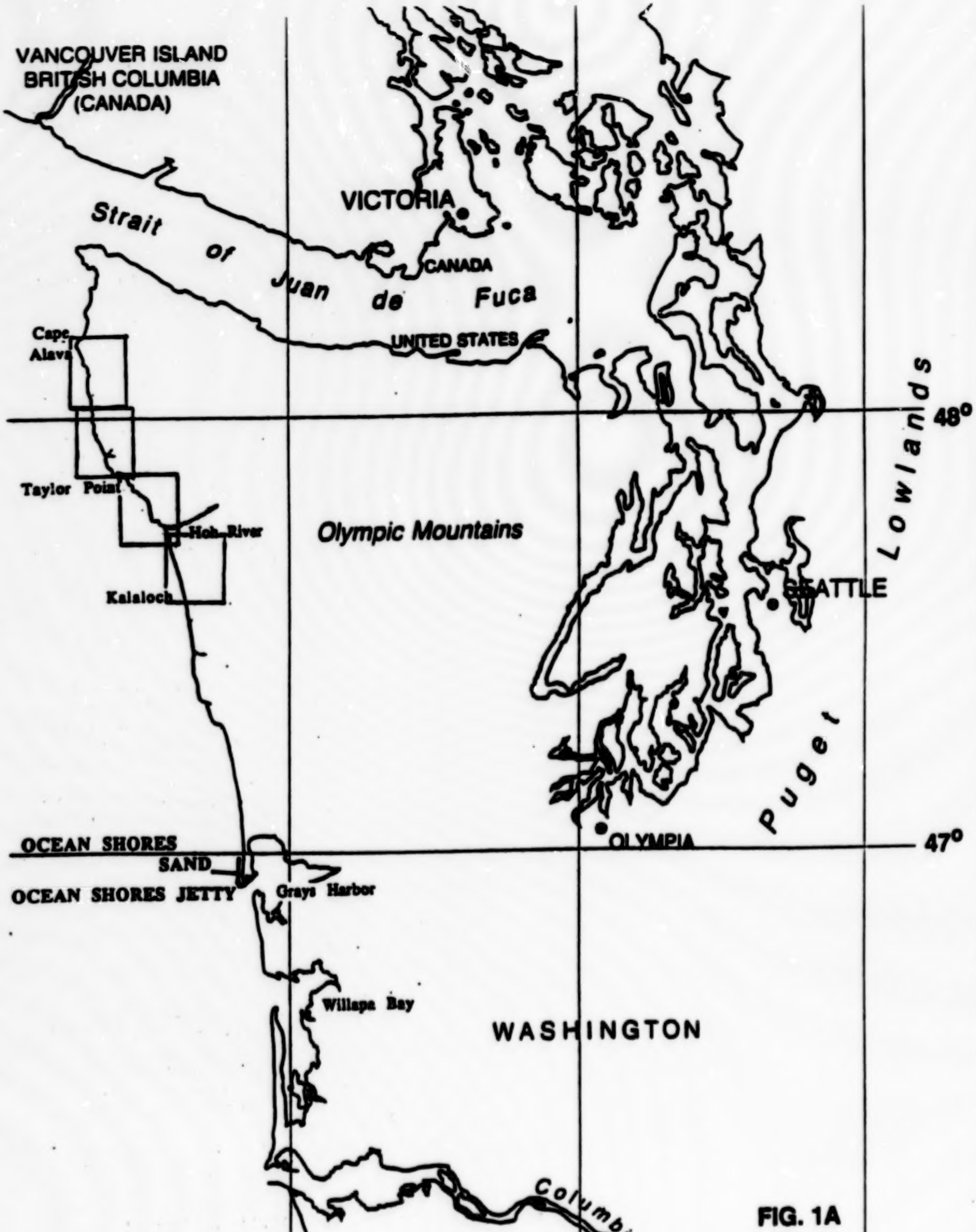

FIG. 1A

Figure 1A. The coast of Washington, with study sites marked, showing the locations of the four detailed maps and of the Ocean Shores transect sites. Lines indicate the approximate compass bearings of each transect.

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Table 1: Data on surveyed sites of all habitat types.

Type of Site	Site Name	Site Code	Oiled?	Number of Transects		Transect Orientation	Wave Exposure	
				perm.	not perm.			
Exposed Rocky								
	Chilean Point	CPE	No	1	0	260° (WSW)	High	
	Second Beach	2BR	Yes	1	0	310° (NW)	Mod.-High	
	Taylor Point	TPE	No	1	1	200° (SSW)	Mod.	
	Ocean Shores Jetty	OSJ	Yes	1	0	0° (N)	Mod.	
Sand-Impacted Rocky								
	Starfish Point	SFR	No	1	0	285° (WNW)	Mod.-High	
	Brown's Point	BPR	No	1	1	290° (WNW)	Mod.-High	
Protected Rocky								
	Cannonball Is.	CBR	No	1	0	240° (SW)	Low-Mod.	
	Chilean Pt.	CPP	No	1	0	215° (SSW)	Low	
	Taylor Pt.	TPP	No	0	1	210° (SSW)	Low	
Cobble								Distance between stations (m.)
	Cape Alava	CAC	No	1	1	273° (W)	Mod.	55
	Sand Point	SPC	Yes	1	0	260° (W)	Mod.	75
	Norwegian Mem. I	NM1	No	1	0	265° (W)	Mod.	55
	Norwegian Mem. II	NM2	Yes	1	0	274° (W)	Mod.	55
	Kayostla	KBC	No	0	1	270° (W)	Mod.	-
	Chilean Pt.	CPC	No	1	0	213° (SSW)	Mod.-High	25

Table 1, cont'd.

Sand						
	Sand Point	SPS	Yes	1	230° (SW)	High
	Cedar Creek	CCS	No	1	250° (WSW)	Mod.
	Second Beach	2BS	Yes	1	215° (SSW)	High
	Ruby Beach	RBS	No	1	260° (W)	High
	Kalaloch	KCS	No	1	260° (W)	High
	Ocean Shores	OSS	Yes	1	275° (W)	High

organisms in each habitat type were surveyed in the winter. Sites sampled in the winter of 1989 were either sampled before (Jan. 6-8) or after (March 6-8) the freeze event (Feb. 1-6).

2.2 METHODS: Rocky Shores

Rocky headlands exposed to the full force of the Pacific Ocean perhaps typify most peoples' concept of the outer coast of Washington. They range from sheer or steep bedrock occupied by only the most wave-tolerant species, to flat benches pocked with pools and susceptible to less wave damage (since much of the energy is removed by the outer edge). The former habitat is found on all of the abundant promontories projecting out into the ocean, and on the sea stacks that are so characteristic of this coastline.

Wave-exposed, rocky shores were sampled at (from north to south) Chilean Point (north of Hole in the Wall), Second Beach, Taylor Point, Kalaloch, and the jetty at Ocean Shores (Table 1, Figure 1A-E). Both sites sampled at Kalaloch, and to a lesser extent the jetty at Ocean Shores, were sand-impacted (Table 1), while the other rocky shores were largely free of sand influence. The sites at Kalaloch were chosen pre-oil-spill; one (Starfish Point) was chosen because of its popularity as a site for intertidal exploration by visitors, and the other (Brown's Point) because it is somewhat isolated from road access and from the beach itself, and is seldom visited by humans.

Transects on more protected rocky shores were run at Cannonball Island (Cape Alava), Chilean Point, and Taylor Point (Figs. 1B-E). Time did not permit the establishment of permanent quadrats at Taylor Point, so the time series of data present from the other sites does not exist for this one.

At the exposed rocky sites, the established transects ran from approximately mean lower low water (MLLW: 0 m datum) to 4 m above MLLW, with quadrats sampled at every meter of vertical rise. More protected transects ran from MLLW to ca. +3 m (with quadrats at every 0.75 m), since the reduced wave action at these sites shrank the vertical extent of the intertidal zone. MLLW was estimated from the day's predicted tide and taking into account the weather (e.g., onshore vs. offshore breeze). Subsequent heights were measured from this point using a hand level and meter sticks. There was some unavoidable variation in the absolute heights of the transects due to errors in this estimation; repeated observations on subsequent dates quantified the heights as precisely as possible. To eliminate variation caused by different rock aspects (e.g., dry south-facing versus damp north-facing), whenever possible we chose west-facing transects; if the headland did not offer such a face, the transect was chosen to face into the prevailing swell.

At each tidal height, five 0.25 m^2 quadrats were sampled (except at Chilean Point, where there were 6), so that there usually were 20 quadrats per transect. At each level we attempted to sample quadrats on emergent (non-pool) rock on surfaces approximating the slope of the transect overall; other than these criteria, quadrat sites were haphazardly chosen. The logistics of avoiding pools and large crevices (which have very different physical regimes and thus different assemblages), and of working on very irregular surfaces, made selecting statistically random quadrats impossible. As the intertidal zone is a notoriously patchy environment, even extensive replicate sampling will only begin to characterize a zone; the level of replication chosen was a compromise between time available and adequacy of sampling.

Permanent quadrats were marked at each level using stainless steel hardware. Some quadrats had been marked in summer 1988 using a 1/4 inch star drill to drill holes 2-3 cm deep in the sandstone at the upper left corner of each quadrat. Into each hole was placed a 1.5 inch long stainless steel round head machine bolt and a 1 inch stainless washer, imbedded in Koppers Splash

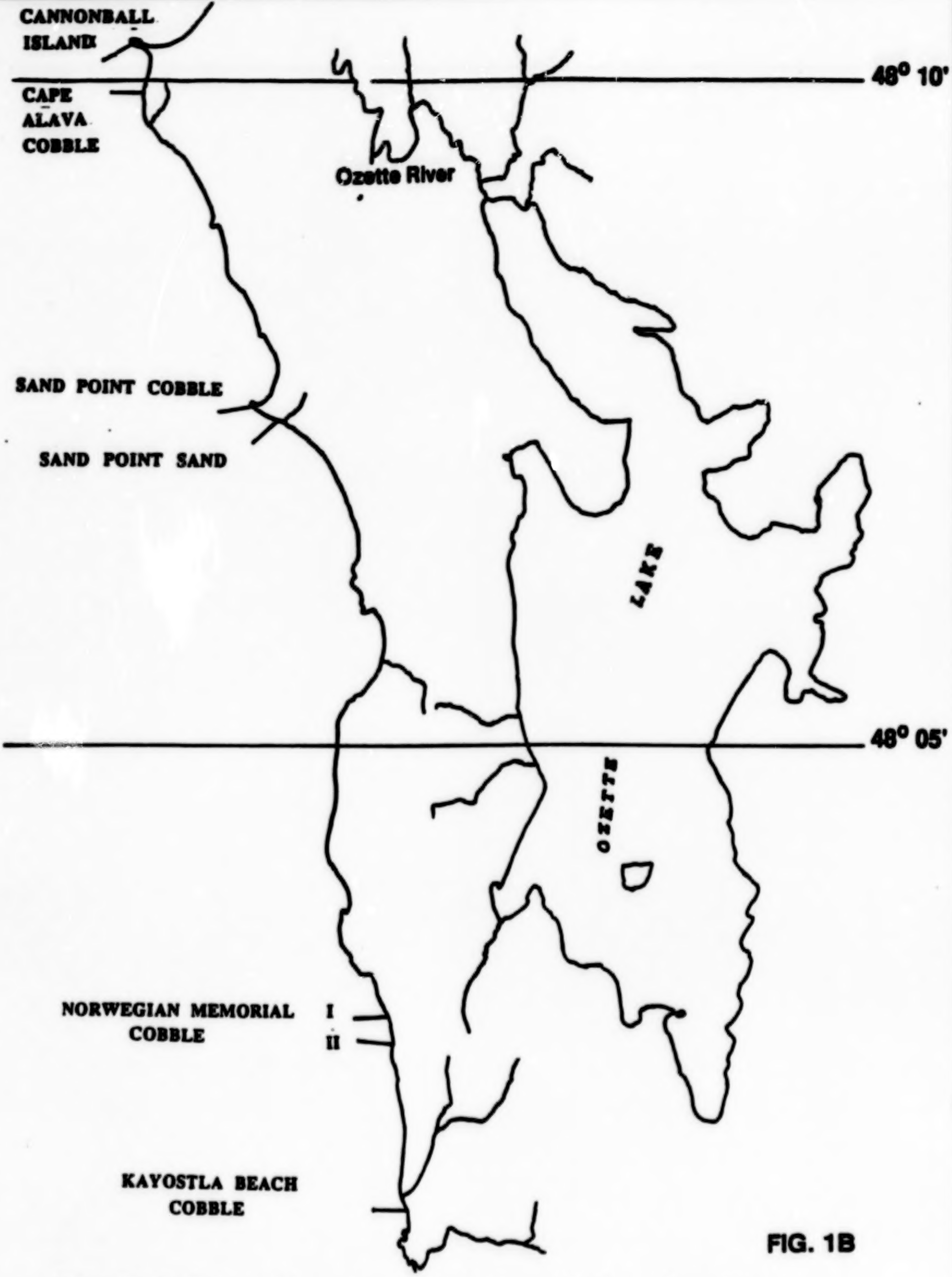

FIG. 1B

Figure 1B. Detailed map of the northern portion of the coast, showing each permanent transect site (lines denote approximate location and compass bearing of each transect).

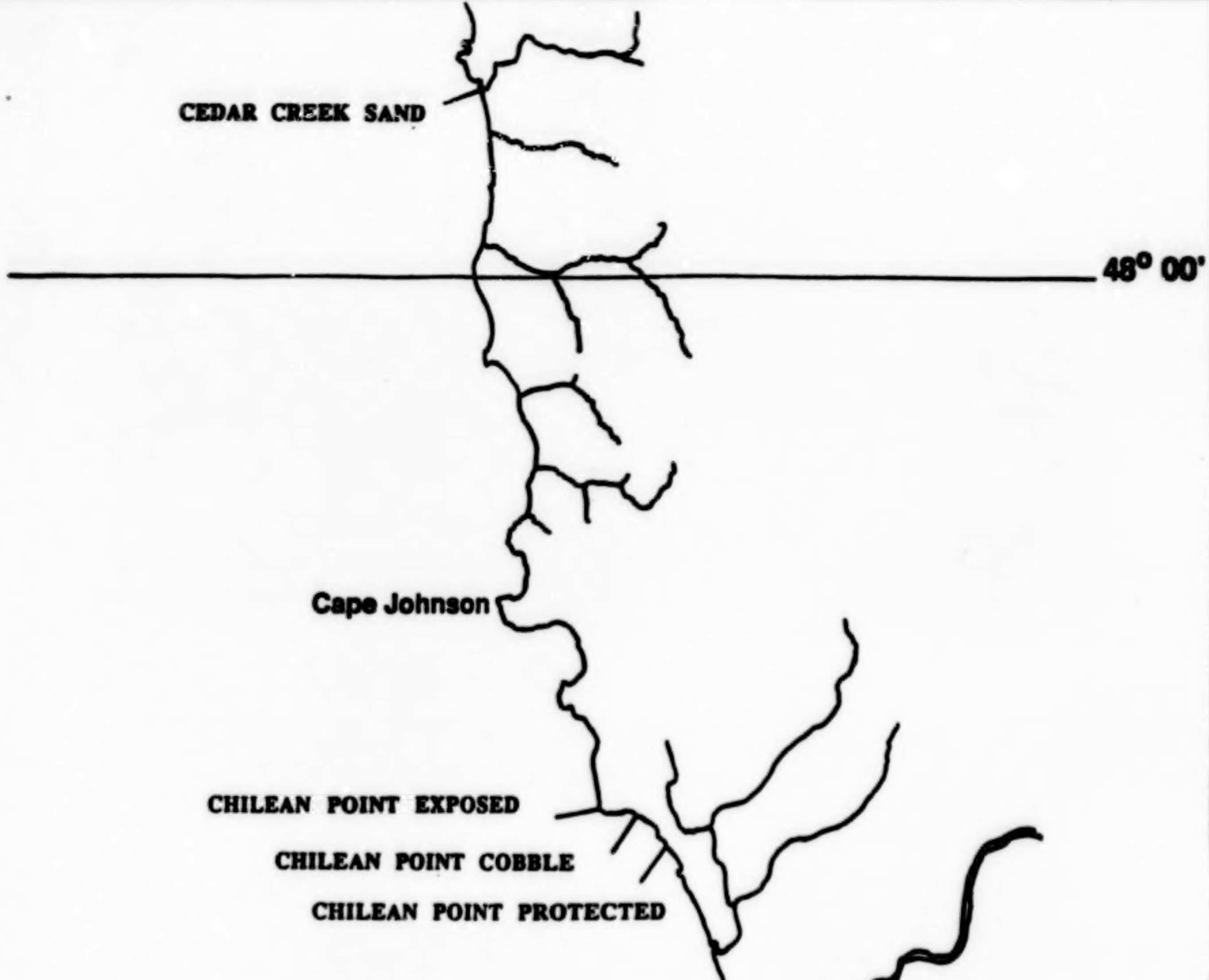

Figure 1C. Detailed map of the north-central portion of the coast, showing each permanent transect site (lines denote approximate location and compass bearing of each transect).

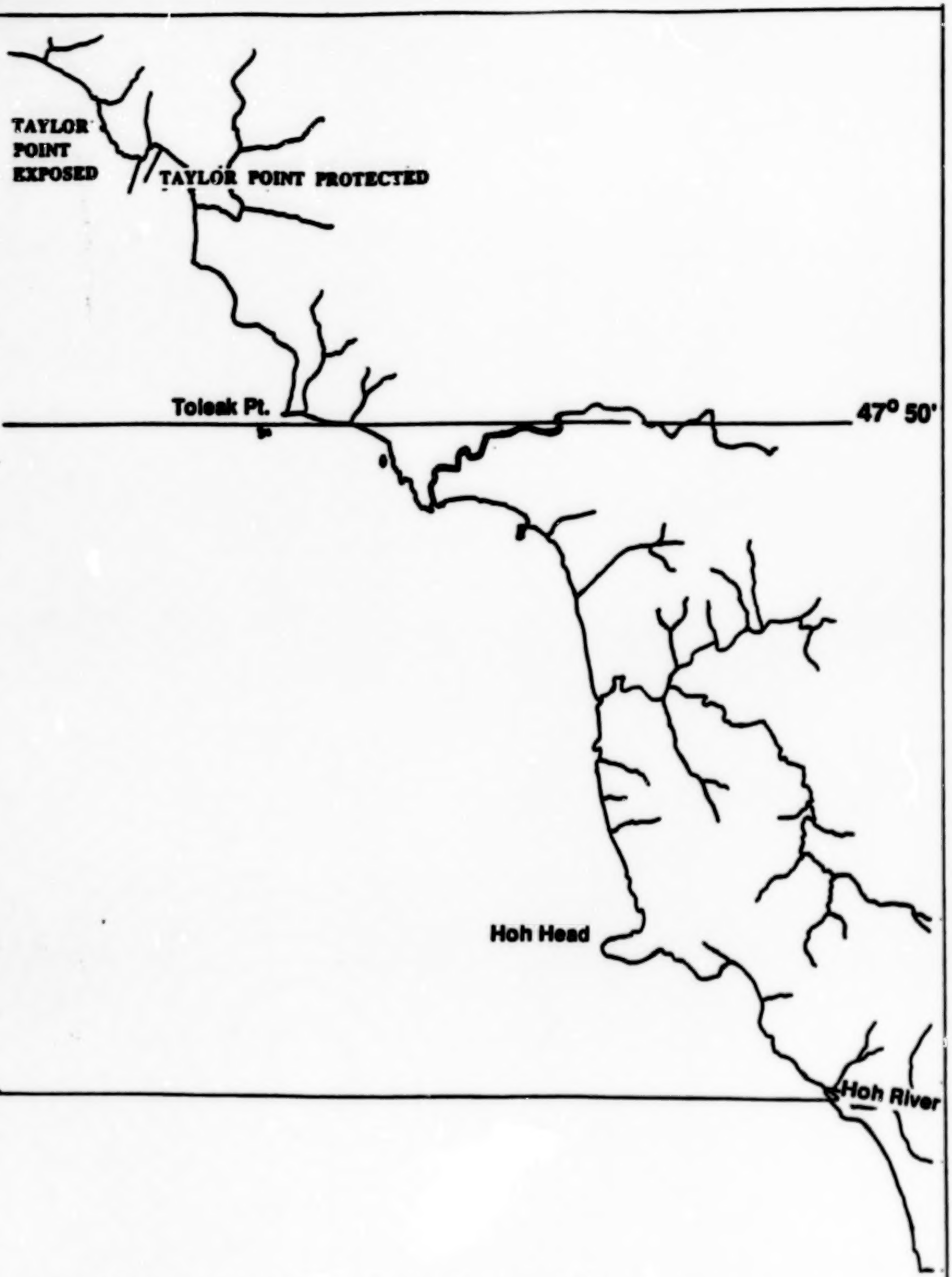

Figure 1D. Detailed map of the central portion of the coast, showing each permanent transect site (lines denote approximate location and compass bearing of each transect).

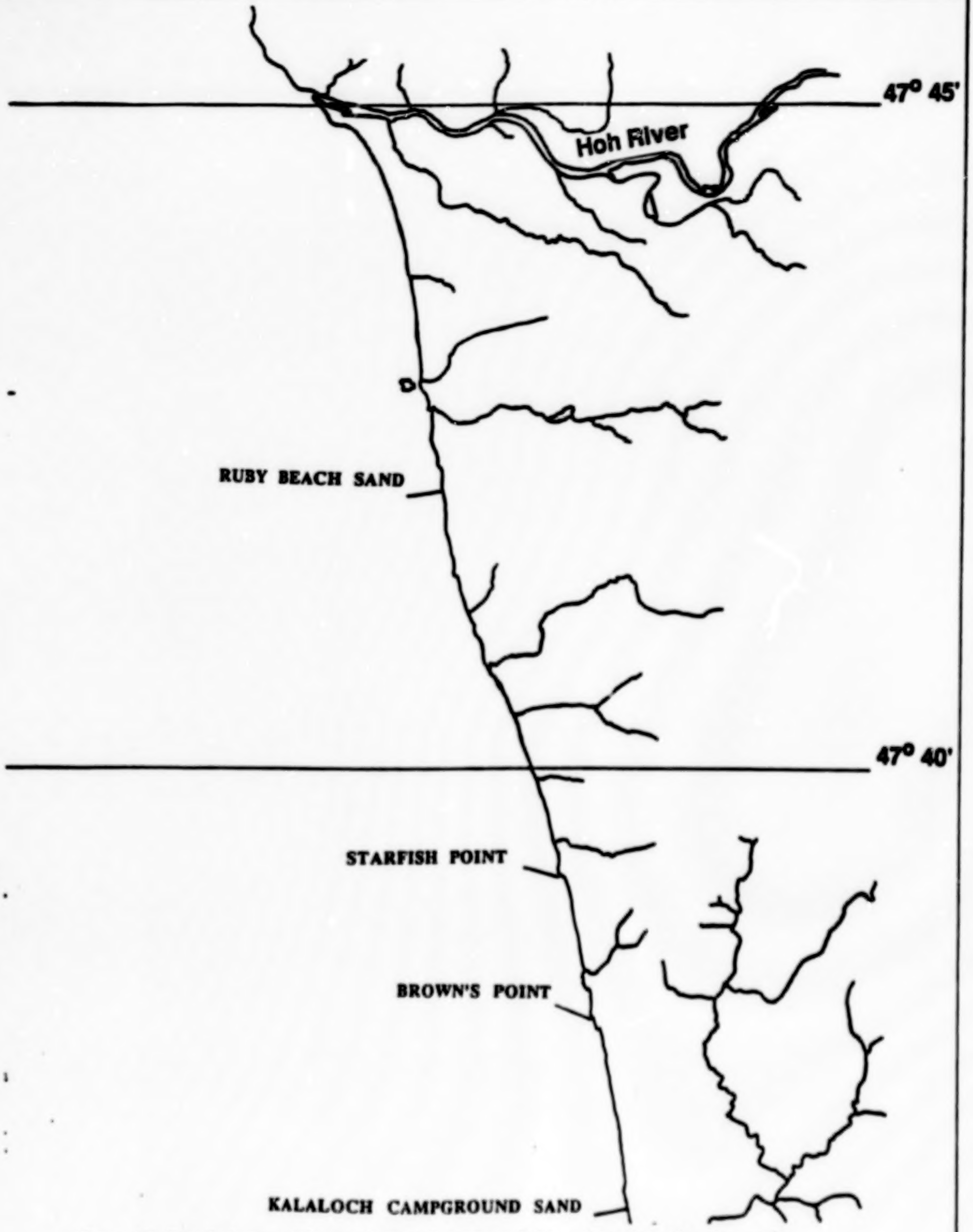

Figure 1E. Detailed map of the south-central portion of the study region, showing each permanent transect site (lines denote approximate location and compass bearing of each transect).

Zone Compound. In 1989 a second bolt was added in the upper right corner of these quadrats, using a gas-powered hammer drill to make holes, and placing a hex-head bolt and 1-inch washer into a plastic sleeve imbedded in the hole. Quadrats first established in 1989 used two of these bolts, and the washer had an identifying letter stamped into it. Compass bearings (Table 1) and descriptions of each transect were also taken.

An attempt was made to quantify and identify all macroscopic organisms in each quadrat. Algal cover was quantified as the percentage of the quadrat surface covered by the canopy of each species; in areas with multilayered algal canopies, the total percent cover thus often exceeded 100%. Sessile invertebrates (e.g., barnacles, mussels, anemones) were also quantified by percent cover. These percentages were estimated with the use of a grid of lines dividing the quadrat into 25 squares of 4% cover each. This method has been found to be more repeatable, accurate, and faster (in limited field time) than other techniques such as random dots (study summarized in Appendix A). Organisms covering less than 1% were recorded as "trace", and arbitrarily assigned 0.5% for analysis. Mobile organisms were counted throughout the quadrat, except for extremely numerous species such as *Littorina*, whose numbers were extrapolated from counts in at least 3 small squares (10x10 cm). To minimize destructive sampling, only unknown organisms were collected, and whenever possible these were removed from nearby rather than from inside the permanent quadrats. Algal samples were pressed in the field, and animals were preserved in 4% formalin. Primary reference works were Gabrielson et al. (1989) for algae and Kozloff (1987) for invertebrates.

Photographs were taken of each quadrat to establish a permanent visual record. A Nikonos V camera and a Sea and Sea strobe were attached to a framer made of PVC pipe and ending in a square the same size as the quadrat; this allowed photographs to be made of the identical site at different times. Photographs were taken from 1 m, usually at f5.6 and 1/60 sec, using Kodachrome 64 slide film. Correct exposures were difficult to obtain, since the ambient light and reflectivity of the algae and rock varied so widely; thus the photographic record contains gaps.

In addition to the quadrat sampling, extensive notes were made on the abundance of organisms between the sampled zones, and on the species seen in pools, surge channels, undersides of boulders, etc. At Chilean Point, Taylor Point, Starfish Point, Brown's Point, and Second Beach we also made counts of *Pisaster* in defined areas (such as on the sides of a huge boulder, or in a certain large pool) near the permanent transects. At low tide, *Pisaster* tend to congregate in large clumps in such areas rather than being spread evenly throughout a transect; thus we often would record few in our quadrats even though they were abundant nearby. These counts give an overall view of the abundances of these animals, but will be useful primarily for examining long-term trends in their abundance.

Lastly, at both Starfish Point and Brown's Point (sand-impacted) we established transects designed to look at densities and trends in abundance through time of the tube worm *Eudistylia*. Each transect was roughly 30 m long, stretching between 2 large stainless bolts imbedded in the rock and running roughly parallel to the shore through the low intertidal zone. All colonies of worms (defined as clumps greater than 8 cm diameter) within 1 m of each side of this line were counted, and their areas approximated via the closest geometric shape. Thus both densities of colonies per 60 m^2 and overall area covered by worms at each site could be quantified.

2.3 METHODS: Cobble Fields

In areas where sea stacks or islands are very near shore and reduce the wave energy hitting the beach, boulders and cobbles which would otherwise be removed by waves form extensive intertidal flats. This unusual (but fairly abundant within the Olympic National Park) habitat contains typical rocky-shore organisms living on the larger boulders, protected-shore organisms living in the lee of large rocks, and soft-sediment organisms living in the substratum beneath the cobbles and boulders. Consequently, these habitats are a sort of hybrid between rocky and unconsolidated shores, and contain both infaunal and epifaunal components; thus they are surprisingly diverse despite their general unprepossessing appearance.

Cobble field transects were set up at Cape Alava, Sand Point, Norwegian Memorial, and Chilean Point (Table 1). A non-permanent transect was also surveyed at Kayostla Beach. Transects ran across the extensive intertidal flats composed of cobbles and small boulders, overlying a combination of bedrock and sediment. This was the most difficult habitat to sample, since it was composed of so many substrate types, and in addition had many areas of standing water (large shallow pools).

Rather than attempting to place quadrats at specific tidal levels at each site (which would have required sophisticated surveying equipment over the long horizontal distances), we sampled 3 replicate quadrats at each of 8 "stations" spaced at equal intervals from the highest zone of organisms down to the water's edge. These stations were thus 50-75 m apart from each other except for at Chilean Point, where the intertidal bench was shorter (Table 1). Each level (=station) was permanently marked with a numbered stainless bolt and washer in some prominent rock. Permanent quadrats could not be established because 1) there would have been no way to mark precise spots in the areas that consisted of unconsolidated substratum, and 2) destructive sampling was necessary at each date in order to examine the organisms under rocks and in the sediment. Thus during each sampling period, quadrats were tossed haphazardly at each station, and we sampled whatever substrate (bedrock, cobble, pool, sediment, etc.) was contacted. In addition, we took extensive notes on the other organisms seen in the area. Photographs were taken of the general area but not of specific quadrats, since these were not permanent.

2.4 METHODS: Sandy Beaches

Beaches composed of unconsolidated sediment from coarse pebbles to fine sands are found along the length of the Washington coastline. Pebble beaches are quite biologically depauperate due to their highly unstable nature and the crushing action of pebbles in waves, and were not sampled. Sandy beaches, while still of extremely low diversity and productivity relative to rocky shores, do contain a surprisingly large number of organisms. In addition, much of the oil that came ashore from the Nestucca spill hit sandy beaches.

Sand transects were established (from north to south) at Sand Point, Cedar Creek, 2nd Beach, Ruby Beach, Kalaloch, and Ocean Shores (Figs. 1A-E). The transect at Kalaloch is heavily human-traveled, as it is in front of a popular campground. The nearby Ruby Beach is much less used by humans. As in the cobble areas, permanent quadrats could not be established because of shifting substratum. Thus the organisms (all infauna) were sampled using the "station" method at each site. Beginning at the lowest workable level (awash at the time of low tide, and varying with site and date), we sampled 10-20 stations evenly spaced up the shore. Distance between stations varied with site and date, depending on available time and slope/length of the beach.

At each level we took 4 cores, 10 cm diameter, using an aluminum "clam gun". In 1988 samples, we separated the shallowest 15 cm of the core from the deepest and counted the organisms in each, sieving these sections separately on 1 mm mesh. For Eohaustorius spp. (amphipod crustaceans), the most common species, only 1.3% were found below 15 cm. Due to the additional time involved in coring and sieving deep samples, subsequent cores only included the top 15 cm; thus we have underestimated the abundance of amphipods slightly. Samples of all unknown organisms were preserved and returned to the laboratory for identification.

The only large (>2 cm) organism in these sediments is the razor clam, Siliqua patula. These clams are found only at the lowest tidal levels and are very patchy, both locally (meters) and along the coast. Only four razor clams were found in the thousands of cores sampled. Digging for these clams is slow, destructive (many get badly damaged by shovels or cores), and imprecise (for sampling such a patchy organism). In 1988 we attempted to estimate densities by using the subtle surface markings the clams leave. While this method appeared to be effective for local sampling (Dethier 1988), it is time consuming and may not give an accurate indication of densities across a whole site. Thus we did not pursue this sampling further. However, the Washington Department of Fisheries, in conjunction with Park biologists are conducting an extensive razor clam monitoring program.

3.0 STATISTICAL ANALYSES

All data except observations of rare species were entered into Rbase System V files, separated by habitat type. For statistical analysis, data were exported into SAS.

The effects of the oil spill on species abundances were compared for each habitat type by comparing abundances at "oiled" and "unoiled" sites. Fmax tests on haphazardly selected data sets showed that variances around mean abundances were significantly non-homogeneous. Thus all data were transformed before analysis; percent covers were arcsine transformed, and counts were log transformed. These transformations eliminated the heteroscedasticity. We tested for oil effects on each species using Summer 1989 data (the sampling date when oil effects should have been clearest), analyzed with fixed-model nested Analyses of Variance, with sites nested under treatments (oiled vs. unoiled), and quadrats serving as replicates within sites. For rocky habitats, each tidal height was analyzed separately. In one set of analyses, we compared all 9 rocky sites. A second analysis was done omitting the protected sites to reduce site-to-site variation. Since so many individual ANOVAs were done, increasing the probabilities of a Type I error, only p values < 0.01 were considered significant.

For cobble habitats, we pooled quadrats at adjacent levels (i.e. level 1 with 2, 3 with 4, and so forth) so that there were enough replicates (N=6) to run an adequate ANOVA. We ran nested ANOVAs on transformed data, as described above. When all sites were used, there was almost always a significant Site Effect; to reduce this bias, a second set of analyses was run omitting the most anomalous site, Kayostla Beach (see below). This left 2 oiled and 3 unoiled sites, resulting in (1, 3) degrees of freedom.

For sand habitats, we likewise pooled adjacent levels (or stations) at a site to increase the replicates per height. Since transects consisted of different numbers of stations (depending on the horizontal extent of the beach), we divided each transect up into Very High, High, Mid, Low, and Very Low levels. In the absence of a reliable, accurate way to quantitatively measure true tidal height in these habitats, distinctions were made depending on the presence or absence of indicator organisms (such as beach hoppers in Very High samples only) and on the lowness of the tide when the low shore was sampled (so that some shores, which were sampled on poorer tides, had no Very Low samples). Measuring true tidal heights would have required expensive surveying equipment. In addition, both substrate and organisms move up and down the shore with the seasons; thus to compare seasonal abundances without comparing different tidal levels, we needed to use biological indicators. Where two adjacent transects were run at a given site, these data were pooled for analysis. Using this technique, most sites had 3-5 stations, or 12-20 replicates, per tidal level. Nested analyses of variance were run on each species as described above. Two partial transects were omitted from analysis; these were a very-coarse sand one at Kayostla Beach, which was sampled in high zones only, and one at Sand Point, where we had no clam gun and thus the unit of sampling was not equivalent.

4.0 RESULTS AND DISCUSSION

4.1 Early Post-Spill Observations

Portions of the coast of Washington were visited on Jan. 6-8, 1989, as the oil spill was still being actively cleaned up. Some of the permanent rocky transects established in summer 1988 were resurveyed at this time, a sandy beach transect was partially resurveyed, and many miles of shoreline were walked looking for immediate oil impact. The rocky sites revisited were Starfish Point, Taylor Point, and Cannonball Island (see Table 1), and the sandy transect was the one at Kalaloch. In addition, we did non-quantitative sampling at Second Beach, which was heavily oiled and covered with cleanup crews. In brief, with the exception of this latter site, none of the 1988 permanent transects or their surroundings received significant quantities of oil, and virtually no oil impacts to the shoreline flora and fauna were seen. Dead seabirds, of course, were readily in evidence along most of the coast. General observations for each region visited are recorded below.

Kalaloch Region

The sand transect in front of the Kalaloch campground showed the usual complement of amphipods, isopods, and worms in the sand, all of which appeared healthy. Virtually no oil was seen on these beaches or on the nearby rocky sites, although 2 dead and 1 sick birds were seen. At Starfish Point, populations of colonial worms, mussels, gooseneck barnacles, algae, and other rock and pool-inhabiting organisms appeared normal.

Taylor Point

A moderate amount of oil was seen on the gravel-sand beach just south of Taylor Point. Logs on the high beach had been splattered with oil, small (thin) slicks were seen in a few places on the water, and rope and other flotsam washed ashore were heavily oiled. Mid-intertidal rocks along this partially protected beach showed the only clear evidence of oil damage that we saw on any rocky shore on this trip: many small patches of oil had stuck to the seaweeds, especially to the red alga Endocladia which has a morphology like a brush and thus was especially susceptible to catching small blobs of oil. These algal patches had a clear oily sheen on and immediately surrounding them, and very likely died subsequently. This damage was quite small scale and patchy, however; we suspect it occurred as the tide was receding over this zone, carrying small patches of oil with it.

The permanent transect at Taylor Point itself, however, appeared to have received no oil. Organisms looked healthy, and were in expected wintertime abundances.

Second Beach

Mid- and high-intertidal zone sand samples from this heavily oiled beach were sieved for crustaceans and worms, as at permanent sand transects. While abundances of organisms were not high, we did find apparently lively amphipods, isopods, and polychaete worms in the samples. Even some of the oiled logs high on the beach had apparently healthy talitrid amphipods (beach hoppers) under them.

Cape Alava

At this site there were many small splatters of oil in the sand, on logs, and on some high rocks; we observed some of the same oiled high-intertidal algae as at Taylor Point. While the spit running from Cape Alava to Cannonball Island had some oil in the drift, the permanent rocky transect at Cannonball was clean and apparently unimpacted. Cursory observations of the cobble area near the Cape Alave cobble transect suggested that this area, too, was not impacted. There were oily sheens on some of the high pool areas among the cobbles, but similar sheens were seen 1.5 years later; we now suspect that these are caused not by the oil spill but by organic degradation of the very large piles of drift algae that accumulate at this site.

Overall, our initial impressions of the sites examined immediately following the oil spill were that the marine plants and animals inhabiting rocky and sandy beaches on this coastline suffered only small damage. The reason that this large spill seemed to do so little damage (except to the seabirds) is that at least along the coast of Washington, the oil came ashore on a high tide under stormy conditions (the same front that caused the *Nestucca* to break loose). The major zone of oil impact was thus the very high, or even supratidal region on rocky shores, and the log/drift line on sandy beaches. Organismal diversity is very low in these zones, and thus immediate impact on abundance, productivity, and diversity of intertidal communities was low. There apparently were no subsequent tides high enough to resuspend much of this oil and carry it to other zones. The extreme stickiness of this oil (as witnessed by its ability to stick to mucus-coated algae) suggests that had suspended oil encountered other intertidal zones, we would have observed residues left behind.

4.2 ROCKY SHORES: HABITAT DESCRIPTIONS

4.2.1 Exposed Rocky Headlands (non-sand impacted)

Rocky headlands where the force of Pacific swells is not abated by offshore rocks or nearshore shallows have an intertidal biota very extended by spray. The following is a general description of the zonation of dominant species in these habitats.

Highest zones are dominated by a thin veneer of maritime lichens (mostly of the genera *Verrucaria* and *Arthopyrenia*), and may be occupied by sparse barnacles (*Balanus glandula*), littorinid (periwinkle) snails (*Littorina sitkana* and *L. tatooshensis*) and semi-terrestrial isopods (*Ligia* spp). The highest intertidal macroalgal zone is dominated by *Iridaea cornucopiae*, mixed in with stunted *Fucus gardneri* and with *Pelvetiopsis* in slightly less wave-exposed areas. At most sites, the "Very High" permanent quadrats were dominated by these species. At some sites the unusual pulmonate "limpet" *Siphonaria* is very abundant in the *Iridaea*. The red alga *Endocladia muricata* is found in slightly more protected areas. Mixed in with the *Iridaea* begins an extensive zone of *Balanus glandula* and sparse individuals of the mussel *Mytilus edulis*.

"High" quadrats in wave exposed areas are totally dominated by mussels, either the large California mussel *Mytilus californianus*, or *M. edulis*. Interspersed are gooseneck barnacles (*Pollicipes polymerus*), acorn barnacles, and limpets (mostly living on the shells of the mussels). In areas of highest wave exposure (e.g. the outsides of sea stacks or offshore islands), the sea palm *Postelsia* lives in the mussel zone (although not in any of the study sites). It can be locally abundant, but its distribution is very patchy and largely unpredictable. Few other algae co-occur in this mussel zone except in small clumps. The lower limit of the California mussel is set by predation by the ochre star *Pisaster ochraceus* (Paine 1966), which often can be seen clumped at the lower edge of this zone, feeding on barnacles and mussels.

Below the mussel bed, and extending down through the "Mid" quadrats, are series of banded or patchy algae: *Endocladia* and *Mastocarpus papillatus* dominate the highest of these zones, then there is a highly diverse zone that may be occupied by *Iridaea splendens*, *Neorhodomela larix*, *Dilsea californica*, *Hedophyllum sessile*, *Corallina vancouveriensis*, or a mixture of these and other species. Often the algae are layered in 3 or more canopies of different species, making this a complex, lush, and highly productive zone. Animals in this zone include barnacles (*B. glandula*, *Semibalanus cariosus*, and *Chthamalus dalli*), limpets (mostly *Lottia pelta*), chitons (*Katharina tunicata* and *Lepidochitona dentiens*), seastars (*Pisaster* and *Leptasterias hexactis*), and anemones (*Anthopleura elegantissima* and *A. xanthogrammica*).

The lowest zones, near mean lower low water, are dominated by various kelp species (depending on the degree of wave exposure), by the surfgrass *Phyllospadix scouleri*, or by multilayered mixtures of algae. Algal diversity and abundance are very high. Some sites have abundant purple urchins (*Strongylocentrotus purpuratus*) in this zone, whereas others have none. The substrate is dominated by algal holdfasts and by red encrusting algae, mostly crustose corallines. These are fed on by the lined chiton *Tonicella lineata*, limpets, and *Katharina*. Hydroids, bryozoans, sponges, tunicates, small gastropods, and many other species shelter beneath the algal canopies.

Tens of other plant and animal species live amongst these dominant organisms. Appendix B gives a complete species list of the plants and animals found at these rocky sites. It includes species found in tidepools (which were not quantitatively sampled) such as *Anthopleura xanthogrammica*, crabs, shrimp, other invertebrates, fishes, and diverse intertidal and subtidal algae.

4.2.2 More Protected Rocky Shores

In areas where the intertidal is a broad bench (e.g., a wave-cut marine terrace) or where offshore rocks or sea stacks blunt some of the force of the waves, very different assemblages of plants and animals occupy the shore. The intertidal zone is less extensive vertically without wave action and spray, and protected areas often contain more pools and surge channels that are occupied by different species than on steep, exposed rocks. Mussels, *Iridaea*, and kelps are rare, and are replaced by *Fucus*, *Mastocarpus*, barnacles, periwinkles, the turban snail *Tegula*, and numerous other species. Surfgrass, which cannot withstand the most extreme waves, tends to be more abundant in protected areas, as is the cloning anemone *Anthopleura elegantissima*. Surfgrass in pools provides a cool, complex environment for many other organisms (Dethier 1984).

Dominant organisms on protected shores are as follows. Generally no macroscopic organisms are found above the "Very High" quadrats, which are dominated by lichens, the fucoids *Fucus gardneri*, *F. spiralis* and *Pelvetiopsis*, the red alga *Endocladia*, *Balanus glandula*, periwinkles, and the limpets *Lottia digitalis* and *L. strigatella*. "High" quadrats are dominated by dense stands of *F. gardneri*, *Endocladia*, and *Mastocarpus papillatus*, various encrusting algae, limpets, littorinids, and *Tegula funebralis*. The green filamentous *Cladophora* spp. may be abundant, and the isopods *Idotea* spp. may be present in the fucoids. "Mid" zones are dominated to a lesser extent by fucoids and have more red algae, especially *Mastocarpus* spp., *Iridaea splendens*, *Endocladia*, *Polysiphonia* spp., and sometimes *Halosaccion glandiforme*. Ulvoids may be abundant, and in areas where there is sand in the low zone there are patches of the brown *Phaeostrophion irregulare*.

"Low" zone dominants depend on the presence or absence of sand in the water column. Sand-free areas (such as at Cannonball Island) have typical low-shore rocky species, including laminarians, *Iridaea*, *Dilsea*, and surfgrass, with a variety of small gastropods and chitons. Sand-impacted low zones (such as at Chilean Point) are dominated by *Sphacelaria* spp., which binds great quantities of sand between its filaments, *Phaeostrophion*, *Dilsea*, *Iridaea*, and sometimes *Neorhodomela* and the kelp *Egregia menziesii*. The small herbivorous gastropods *Lacuna* spp. may be very abundant.

At a few sites, the importance of wave exposure in controlling species and abundances was readily seen where exposure varied along a short distance. The best example was at the Second Beach rocky site, where the dominant swells tend to hit the transect area from the side, so that the westernmost quadrats are slightly more exposed than the easternmost ones. In the "Mid" quadrats, the exposed quadrats have healthy clumps of *Dilsea*, *Corallina*, and the kelp *Hedophyllum*, numerous *Katharina*, *Pisaster*, and *Anthopleura xanthogrammica*. In the less exposed ones the *Hedophyllum* and *Dilsea* are replaced by *Iridaea splendens*, *Microcladia borealis*, and *Polysiphonia* spp., there are fewer chitons and *Pisaster*, and more *A. elegantissima* and isopods.

4.2.3 Sand-Impacted Rock

A poorly understood habitat occurs where rocky outcrops lie adjacent to or in the middle of high-energy sand beaches, so that rocky surfaces are scoured by (and low rocks periodically inundated with) sand. In Olympic National Park, such habitats are most prevalent in the Kalaloch region, but also are scattered in the pocket (and longer) sandy beaches all the way up the coast. While all rocky shores on this coastline are disturbed by waves and by floating logs, sand-impacted rocks suffer additional physical disruption from this scouring action. Organisms living here are either those that can withstand temporary burial by sand and have tough enough tissues to survive scouring, or whose life histories enable them to recruit, grow, and reproduce in between seasons of heavy sand impact. As a result of these limitations, these habitats are less diverse than non-sand-impacted shores, but do contain an interesting set of species, some of which are not found elsewhere.

Very high zones, where sand impact is less strongly felt, tend to be dominated by the same species that are found on other rocky shores: *Iridaea cornucopiae* and small *Fucus* very high, then barnacles, then *Mytilus* spp. and *Pollicipes*. Lower zones, however, are substantially less diverse than comparable zones on other shores, and have more bare space. "Mid" quadrats are dominated by barnacles (4 species), the cloning anemone *Anthopleura elegantissima*, small *Mytilus edulis*, and juvenile limpets. Barnacles and small limpets can recruit regularly and densely, and evidently benefit from the bare space and diatom growth common in disturbed conditions. Some mid-low areas are covered with solid masses of *A. elegantissima*, which is known to be sand-resistant (Taylor and Littler 1982); they can attach to the rock and extend up through shallow sand, or survive buried under deep sand for months. "Low" quadrats are dominated by encrusting algae, anemones, the red algae *Dilsea*, *Iridaea*, *Pterosiphonia* spp., and *Polysiphonia* spp., and in some areas by the sand-loving kelp *Laminaria sinclairii*, clumps of sabellid worms, and mats of amphipods in sandy tubes. Two other unusual features of these sand-impacted areas are the abundance of chitons of the genus *Mopalia*, which evidently thrive in the presence of sand, and of the gregarious tube worm

Eudistylia, which is found in abundance only in these habitats.

4.2.4 Site to Site Variation (Rocky Shores)

The rocky intertidal zone of Washington state is probably one of the most complex and diverse shores in the U.S. Overall, 97 species of plants and 130 species of animals were found at the rocky sites (Appendix B). This is a highly conservative estimate of organismal diversity, since some groups were consistently under-sampled due to logistic constraints and taxonomic difficulty. With some exceptions, we lumped most gammarid amphipods (there are probably over 20 species), "spider crabs" (family Majidae), encrusting bryozoans, erect bryozoans, colonial ascidians, and families of fishes. Certain difficult algal groups were treated similarly (see taxa listed as "spp." in Appendix B), and some were not counted at all (e.g., colonial benthic diatoms). This count does not include the birds, raccoons, river and sea otters, seals, and deer that forage in or haul out on the intertidal zone, nor the various species of plants that probably live just offshore and were occasionally found as drift on the beaches.

The nested ANOVAs provided information on the extent of site to site variation in the abundances of individual species. All species except those that were rare at all sites, or present at only one site, were analyzed. Table 2 shows the number of species tested which showed significant site variation, both with the protected sites included and excluded. In each case, a large proportion of the species did vary significantly. Those that did *not* show site to site variation in abundance (protected excluded) were mostly those with only very low abundances at all sites (21 cases), or those with very high variance within a site (thus making site to site differences insignificant) (11 cases). Only in 8 cases was there not a significant effect because abundances were actually fairly similar among sites.

Much more research would be required to explain all the site to site differences in diversity and abundance of plants and animals. Wave exposure is clearly critical, since the dominant species (described above) obviously are quite different at exposed and protected areas. The precise reasons why organisms such as *Mytilus californianus* and *Iridaea cornucopiae* require high wave exposure remain obscure. Sand impact is another factor that clearly affects species, especially in the mid and low intertidal zones. Species dominant in the low zones of sand-impacted areas were completely different from those at non-sand sites. The Ocean Shores site was anomalous in a variety of ways (see below). Other differences are more subtle. The Taylor Point site, which was judged as "exposed" because of absence of offshore rocks and the difficulty of working in the low zone, shares a number of characteristics with more protected areas. These include lack of *Iridaea cornucopiae*, very broad zones of *Endocladia* and *Anthopleura elegantissima* in the mid intertidal, and dominance of *Phyllospadix* and *Alaria* in low zones rather than *Laminaria* and *Lessoniopsis* (data in Tables 6-9). Similarly, the Second Beach site, as mentioned above, had some quadrats that were slightly more wave protected and were dominated by different species. The low zone at this site shared some characteristics with sand-impacted areas (the sandy beach is nearby at this site), such as *Laminaria sinclairii* in some low quadrats.

In the same fashion, there was variation among the "protected" sites (data in Tables 11-14). The mid and high intertidal zones of the Cannonball Rock site were fairly similar to those at Chilean Point Protected and Taylor Point Protected. However, the very high zones were quite different (virtually bare at CBR but not elsewhere), and the low zones at the latter sites were fairly calm and sand-impacted, while at the former site the low quadrats were rather wave exposed. Table 3 illustrates the amount of overlap in dominant species among the various sites, and shows that in general, the rocky habitats

Table 2: Proportion of common species showing significant site to site variation in abundance at rocky sites. Significant = $p < 0.05$ level from nested ANOVAs (transformed S89 data), testing differences among sites within a treatment. The last column excludes the protected sites from analysis.

Level	All Sites	Omitting Protected
Very High	16/16	12/16
High	21/24	11/24
Mid	36/40	30/40
Low	36/40	27/40

Table 3: Number of dominant rocky intertidal species held in common between pairs of sites. Site codes are listed in Table 1. "Dominant" species for each site were the four with the highest percent cover (plant or animal) and the two with the highest numerical count (Summer '89 data). Site codes are: TPP= Taylor Point protected, CPP= Chilean Pt. protected, CBR=Cannonball Rock protected, TPE= Taylor Pt. exposed, SFR= Starfish Pt. rock, BPR= Brown's Pt. rock, CPE= Chilean Pt. exposed, 2BR= 2nd Beach rock, OSJ = Ocean Shores Jetty.

Level	TPP-CPP	CPP-CBR	TPP-CBR	TPP-TPE	SFR-BPR	SFR-TPE	TPE-CPE	CPE-2BR	TPE-2BR	2BR-OSJ	OSJ-SFR	OSJ-BPR
V. High	4	0	0	6	4	5	2	2	3	1	5	3
High	5	3	4	1	6	4	3	4	4	4	4	4
Mid	4	3	2	2	3	2	1	3	2	3	3	1
Low	3	2	2	1	3	2	2	3	4	2	3	2
Total	16	8	8	10	16	13	8	12	13	10	15	10

sorted out into 1) exposed rocky (TPE, CPE, 2BR), 2) sand-impacted rocky (SFR, BPR, OSJ), and 3) protected rocky (TPP, CPP, CBR). These site to site differences, despite our attempt to minimize them, make interpretation of treatment effects difficult.

Distributions undoubtedly also are affected by small scale habitat differences, such as those provided by surge channels moving water higher up the shore or steep slopes resulting in more spray. North versus south facing surfaces are visibly different, although we attempted to confine most sampling to west or south faces to minimize this variation (Table 1). Microhabitats provided by pools and underhangs were often occupied by species seen nowhere else, especially by subtidal species that can survive intertidally only in these cool and damp areas. These species are included in the species lists (Appendix B), but were not sampled quantitatively.

4.2.5 Special Species (Rocky Shores)

Table 4 shows the year to year variation in abundance of *Pisaster ochraceus* at four sites, with several areas sampled at two of the sites. Year to year variation is extremely high, but there is no general trend towards either declines or increases through time. Even samplings done one month apart in identical areas showed great changes (e.g., SFR(4)); this may relate to food availability or to weather (with drying conditions driving the seastars into lower areas). The only consistent trend is that counts were lower in the winter; observations suggest that the seastars move lower into the intertidal zone during this season, thus taking them out of the surveyed areas.

Table 5 shows the year to year changes in abundance of the tube worm *Eudistylia* in three transects. Part of the area at Starfish Point is readily accessible to the thousands of visitors who investigate this site each summer, while the other part is across a surge channel and is less visited. The Brown's Point site is a long walk from the highway and is accessible only at very low tide, so is rarely visited. Olympic National Park personnel have long been concerned about the taking of these tube worms for fishing bait, and began stopping this practice (when observed) in 1988. A 1987 study at Starfish Point by G. Berntson quantified predation by humans on the worm, and found it to be significant. Human disruption of worm colonies also made the colonies more susceptible to additional predation by gulls. Table 5 shows that at Starfish Point, both overall colony area and mean colony size were an order of magnitude higher at the less accessible site than the more accessible. The transect at Brown's Point, which is even less accessible than the second site at Starfish Point, had a more even size distribution than either of the other sites, and showed fairly large colony sizes and area covered. Abundances tended to decline from 1988 - 1990 at all three sites, but the changes were most dramatic at the most accessible site. This suggests that conditions have not been good for *Eudistylia* over the last three years, but also that humans are still having a negative impact on colonies at Starfish Point.

4.2.6 Seasonal Changes in Species Abundance on Rocky Shores

Since for most sites we have only one winter sampling date, a statistical analysis of seasonal variation is not possible. Figures 2-18 show trends towards seasonal variation in a number of the broadly abundant species. Overall, 13/27 of the species common on rocky shores showed predictable seasonal patterns at some tidal level. In many cases, judgment about a seasonal effect was compounded by large losses in cover following the February 1989 freeze (discussed below).

Table 4. Numbers of Pisaster found in distinct areas at nine locations. Site codes are: TPE= Taylor Point exposed, CPE= Chilean Point exposed, BPR= Brown's Point, 2BR= Second Beach, and SFR= Starfish Point. The same regions were counted each summer (S88= summer 1988, etc.), and where possible, at least once in the winter. At SFR sampling was done by Bruce Moorhead (Olympic National Park), and includes two counts one month apart for summer 1990. Areas sampled were not measured, so density estimates are not available.

Site	S88	W89	S89	S90	Site description
TPE (1)	275	35	139	162	sides of large boulder
TPE (2)	53	6	41	120	mid-intertidal pool
CPE	100	28	78	76	mid-intertidal channel
BPR	89	11	16	30	side of surge channel
2BR	- -	- -	450	831	mid-intertidal platform
SFR (1)	232	- -	238	283/248	sloping platform with pools
SFR (2)	108	- -	168	257/177	large boulder
SFR (3)	131	- -	154	265/206	large boulder
SFR (4)	74	- -	137	231/648	large boulder

Table 5. Change in abundance of the sabellid tube worm *Eudistylia* at three sites over three years. Data are given as total area of clumps within 1 m along each side of the transect line, as number of colonies in this area, and as mean size of the colonies. Accessibility refers to human access (see text).

Site Name	Accessibility	Transect Length (m)		Total cm^2 worm colonies Summer 88	Summer 89	Summer 90
Starfish Point 1	High	16	total area	2,060	2,730	760
			no. of colonies	10	10	6
			mean size	206	193	105
Starfish Point 2	Mid	13	total area	20,120	17,750	14,560
			no. of colonies	7	7	5
			mean size	2874	2535	2912
Brown's Point	Low	27	total area	28,160	28,397	24,240
			no. of colonies	26	32	26
			mean size	1083	916	932

In "Very High" quadrats (Figs. 2-6), no algae showed consistent seasonal trends (although many suffered in the freeze, see below). Most barnacles (Fig. 4), as well as Mytilus edulis (Fig. 5), also simply showed high, inconsistent variation in abundance. However, the small snails Littorina scutulata and the limpets Lottia digitalis and L. strigatella (Fig. 6) both showed a tendency to be less abundant in the winter. These may be migrating to higher levels or into crevices and other refuges to escape both the cold and the waves of wintertime.

In "High" quadrats, Fucus (where present, in the protected areas) underwent distinct seasonal declines in the winter (Fig. 7). Since Fucus has a weakly attaching holdfast, it is not surprising that populations were reduced by winter storms. None of the other algae (not graphed) showed consistent seasonal changes, although Endocladia at Chilean Point Protected showed large declines simultaneously with the Fucus there. Among the animals, Balanus glandula and Mytilus edulis showed a tendency to decline in winter at some sites (Figs. 9,10); this could be due either to storms or to predators able to forage higher in the intertidal during the winter, when desiccation is reduced. However, none of the other barnacle species at this height (Semibalanus cariosus, Chthamalus dalli, and Pollicipes polymerus) or Mytilus californianus showed a similar trend. As in the very high quadrats, Littorina scutulata declined in abundance in the winter in the wave exposed sites (Fig. 8). Periwinkles in protected sites showed no such pattern (Fig. 8). The limpet species which declined in the winter in the very high quadrats also declined in the high quadrats, but only at two of the five exposed sites (Fig. 11). No pattern was seen in the two protected sites. Juvenile limpets (<5 mm) tended to be more abundant in the winter at sites where any trend was evident (Fig. 10).

In "Mid" quadrats, Fucus again showed dramatic winter declines where present (Fig. 12), as did Dilsea californica (Fig. 13), Endocladia, and Iridaea splendens (Fig. 14). Other algae species were highly variable (e.g., Polysiphonia spp., erect corallines, and Hedophyllum, Figs. 12,13), with no trends evident. All three barnacle species also were highly variable between seasons, sites, and years, and are not graphed. The periwinkle Littorina scutulata again tended to decline in winter (Fig. 15).

In "Low" quadrats, a number of algae showed distinct winter declines, presumably caused by waves and/or by natural winter senescence. These include Dilsea californica, Hedophyllum sessile, Alaria sp., Iridaea splendens, Polysiphonia spp., and Laminaria sinclairii (Figs. 16-18). The latter species clearly senesces in the winter, with most of its blades vanishing. Other algae, such as Mastocarpus, Microcladia borealis, and encrusting corallines showed no patterns. None of the dominant animals showed distinct seasonal patterns (e.g., Chthamalus, Fig. 18).

4.2.7 Year to Year Differences (Rocky Shores)

Figures 2-18 are also illustrative of the high degree of year to year variation in abundances of organisms in permanent quadrats. While some of this variation can be attributed to the freeze (or perhaps to the oil spill -- see below), much appears to be haphazard variation. Such changes will depend on the degree of disturbance suffered by each population (e.g., from wave action or desiccation), the intensity of recruitment of larvae or spores of species and of their competitors or predators, the effects of weather on foraging ability of consumers, and other stochastic factors. Many of these same factors contribute to the high quadrat-to-quadrat variance seen for most species (e.g., see variances in Tables 6-10). Below we discuss the more comprehensible of these effects.

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Figure 2. Seasonal and freeze-induced changes in organismal abundance in Very High rocky quadrats. S88 = summer 1988 sampling, W89 = winter 1989, etc. Site code names are: BPR= Brown's Point, SFR= Starfish Point, TPE= Taylor Point exposed, CPE= Chilean Point exposed, CPP= Chilean Point protected, 2BR= Second Beach, OSJ= Ocean Shores Jetty. Arrows indicate the time of the Feb. 1989 freeze relative to the sampling date: the winter 1989 sampling date was before the freeze (Jan.) at some sites some sites, and after the freeze (March) at others. Sampling at a number of sites did not begin until Summer 1989.

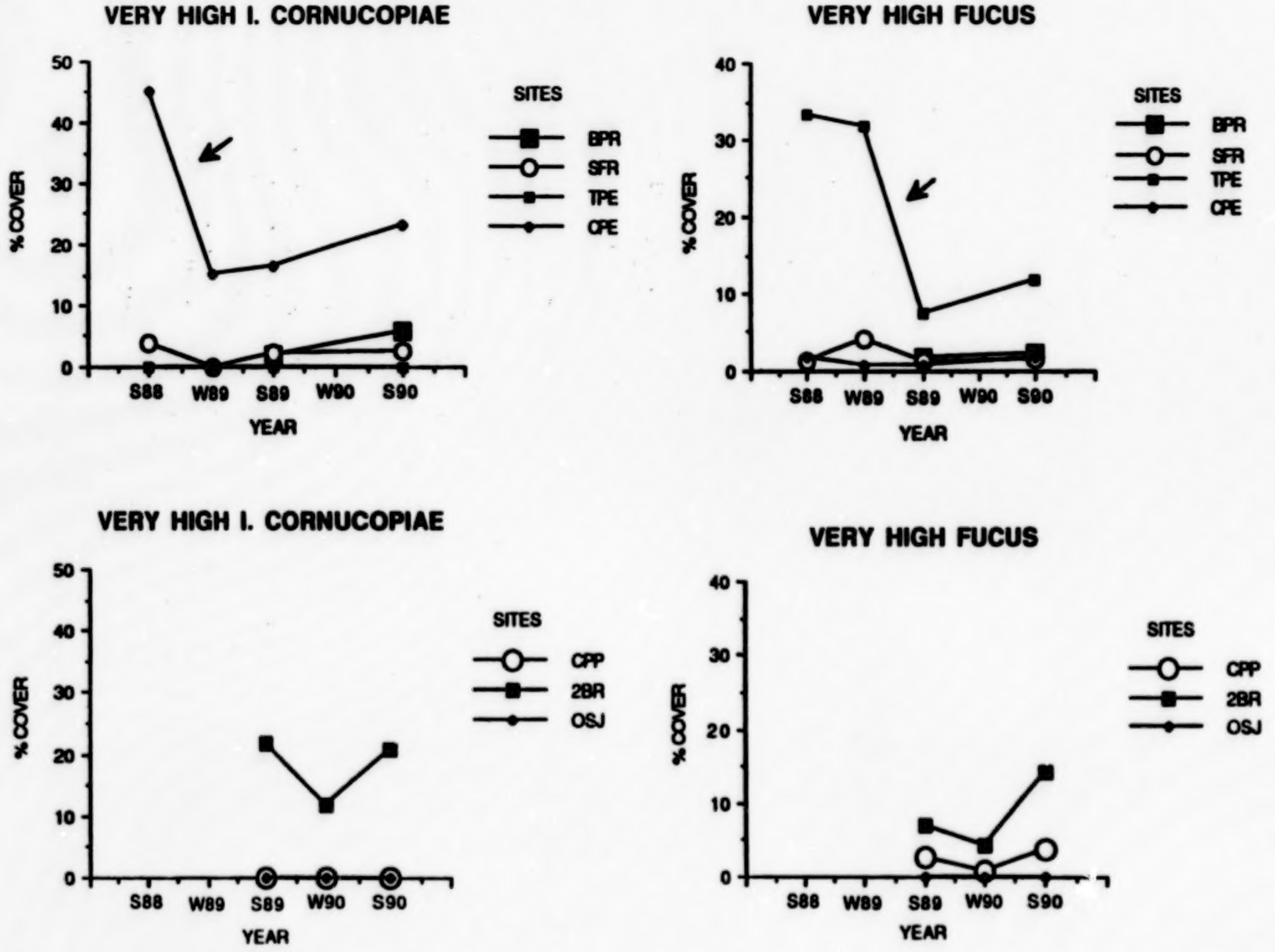


Figure 3. Seasonal and freeze-induced changes in organismal abundance in Very High rocky quadrats. S88 = summer 1988 sampling, W89 = winter 1989, etc. Site code names are: BPR= Brown's Point, SFR= Starfish Point, TPE= Taylor Point exposed, CPE= Chilean Point exposed, CPP= Chilean Point protected, 2BR= Second Beach, OSJ= Ocean Shores Jetty. Arrows indicate the time of the Feb. 1989 freeze relative to the sampling date: the winter 1989 sampling date was before the freeze (Jan.) at some sites some sites, and after the freeze (March) at others. Sampling at a number of sites did not begin until Summer 1989.

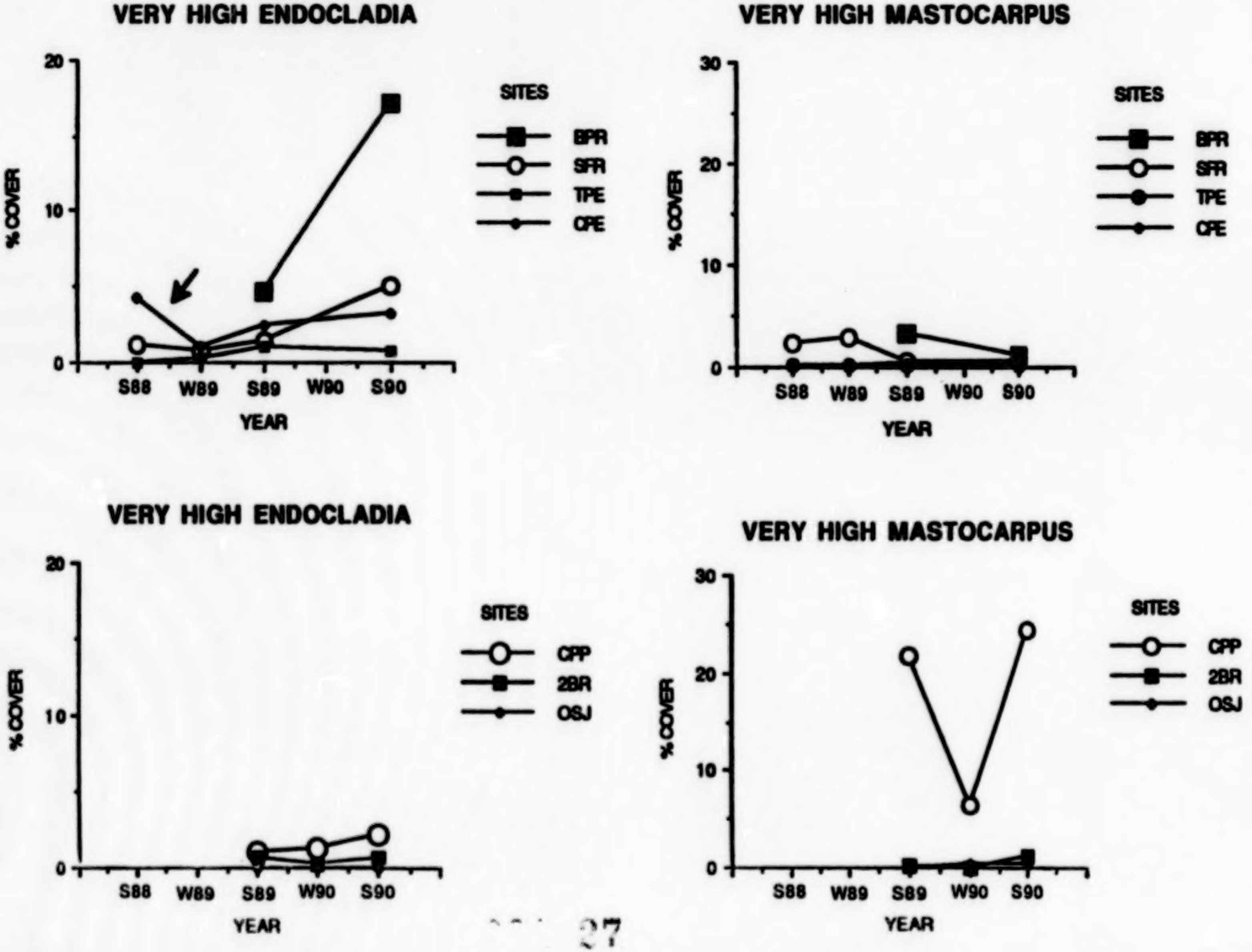


Figure 4. Seasonal and freeze-induced changes in organismal abundance in Very High rocky quadrats. S88 = summer 1988 sampling, W89 = winter 1989, etc. Site code names are: BPR= Brown's Point, SFR= Starfish Point, TPE= Taylor Point exposed, CPE= Chilean Point exposed, CPP= Chilean Point protected, 2BR= Second Beach, OSJ= Ocean Shores Jetty. Arrows indicate the time of the Feb. 1989 freeze relative to the sampling date: the winter 1989 sampling date was before the freeze (Jan.) at some sites some sites, and after the freeze (March) at others. Sampling at a number of sites did not begin until Summer 1989.

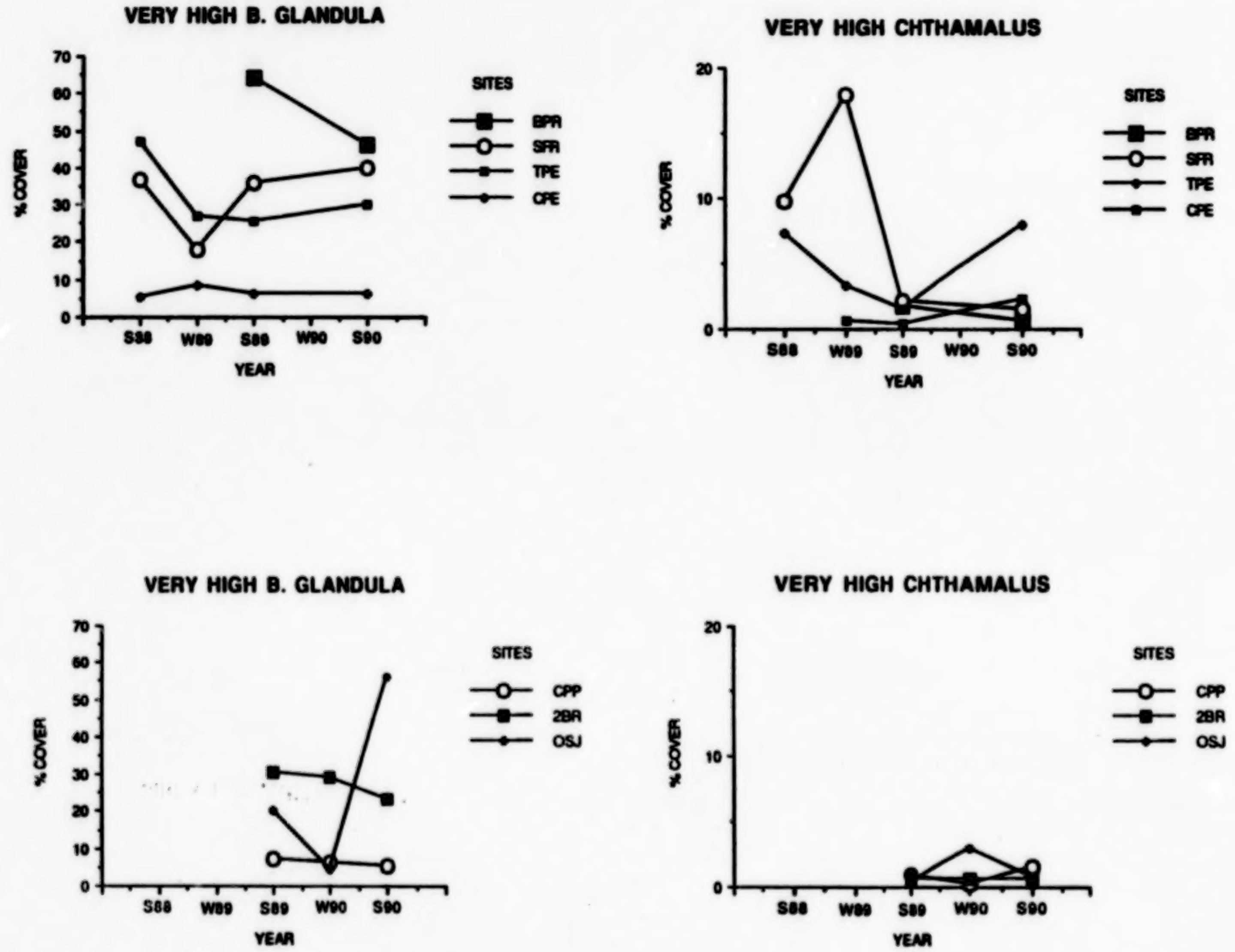


Figure 5. Seasonal and freeze-induced changes in organismal abundance in Very High rocky quadrats. S88 = summer 1988 sampling, W89 = winter 1989, etc. Site code names are: BPR= Brown's Point, SFR= Starfish Point, TPE= Taylor Point exposed, CPE= Chilean Point exposed, CPP= Chilean Point protected, 2BR= Second Beach, OSJ= Ocean Shores Jetty. Arrows indicate the time of the Feb. 1989 freeze relative to the sampling date: the winter 1989 sampling date was before the freeze (Jan.) at some sites some sites, and after the freeze (March) at others. Sampling at a number of sites did not begin until Summer 1989.

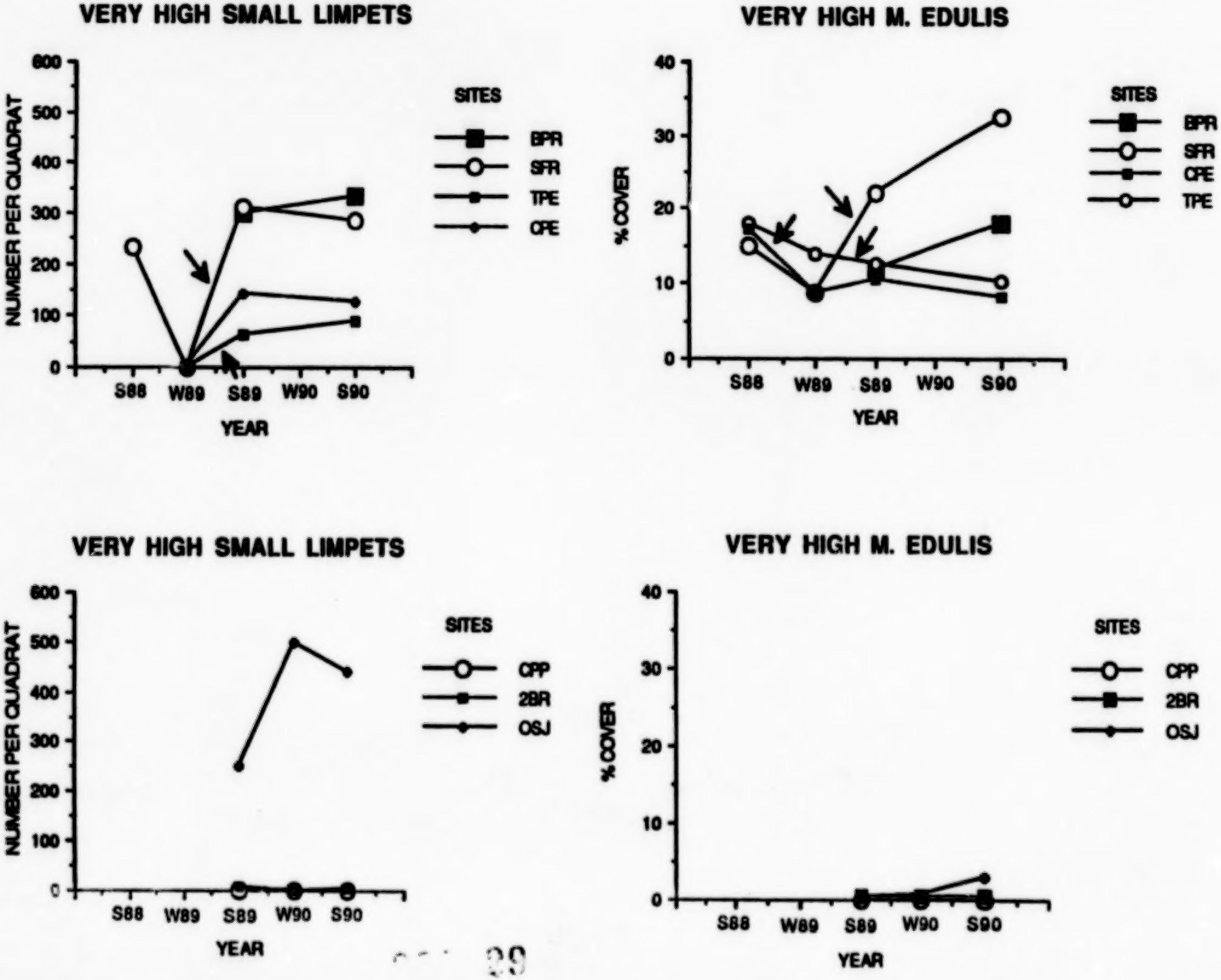


Figure 6. Seasonal and freeze-induced changes in organismal abundance in Very High rocky quadrats. S88 = summer 1988 sampling, W89 = winter 1989, etc. Site code names are: BPR= Brown's Point, SFR= Starfish Point, TPE= Taylor Point exposed, CPE= Chilean Point exposed, CPP= Chilean Point protected, 2BR= Second Beach, OSJ= Ocean Shores Jetty. Arrows indicate the time of the Feb. 1989 freeze relative to the sampling date: the winter 1989 sampling date was before the freeze (Jan.) at some sites some sites, and after the freeze (March) at others. Sampling at a number of sites did not begin until Summer 1989.

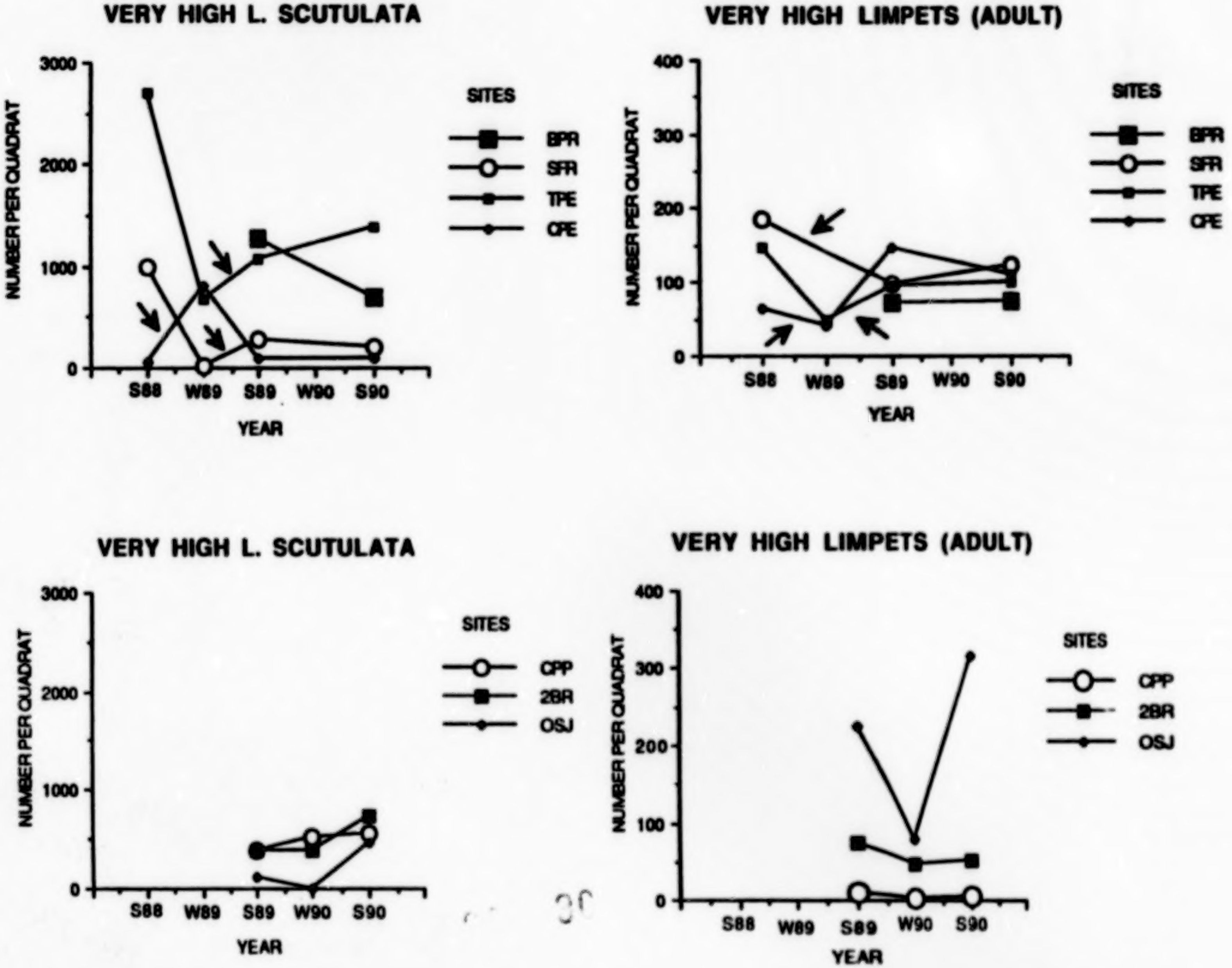


Figure 7. Seasonal and freeze-induced changes in organismal abundance in High rocky quadrats. S88 = summer 1988 sampling, W89 = winter 1989, etc. Site code names are: BPR= Brown's Point, SFR= Starfish Point, TPE= Taylor Point exposed, CPE= Chilean Point exposed, CPP= Chilean Point protected, CBR= Cannonball Island, 2BR= Second Beach, OSJ= Ocean Shores Jetty. Arrows indicate the time of the Feb. 1989 freeze relative to the sampling date: the winter 1989 sampling date was before the freeze (Jan.) at some sites some sites, and after the freeze (March) at others. Sampling at a number of sites did not begin until Summer 1989.

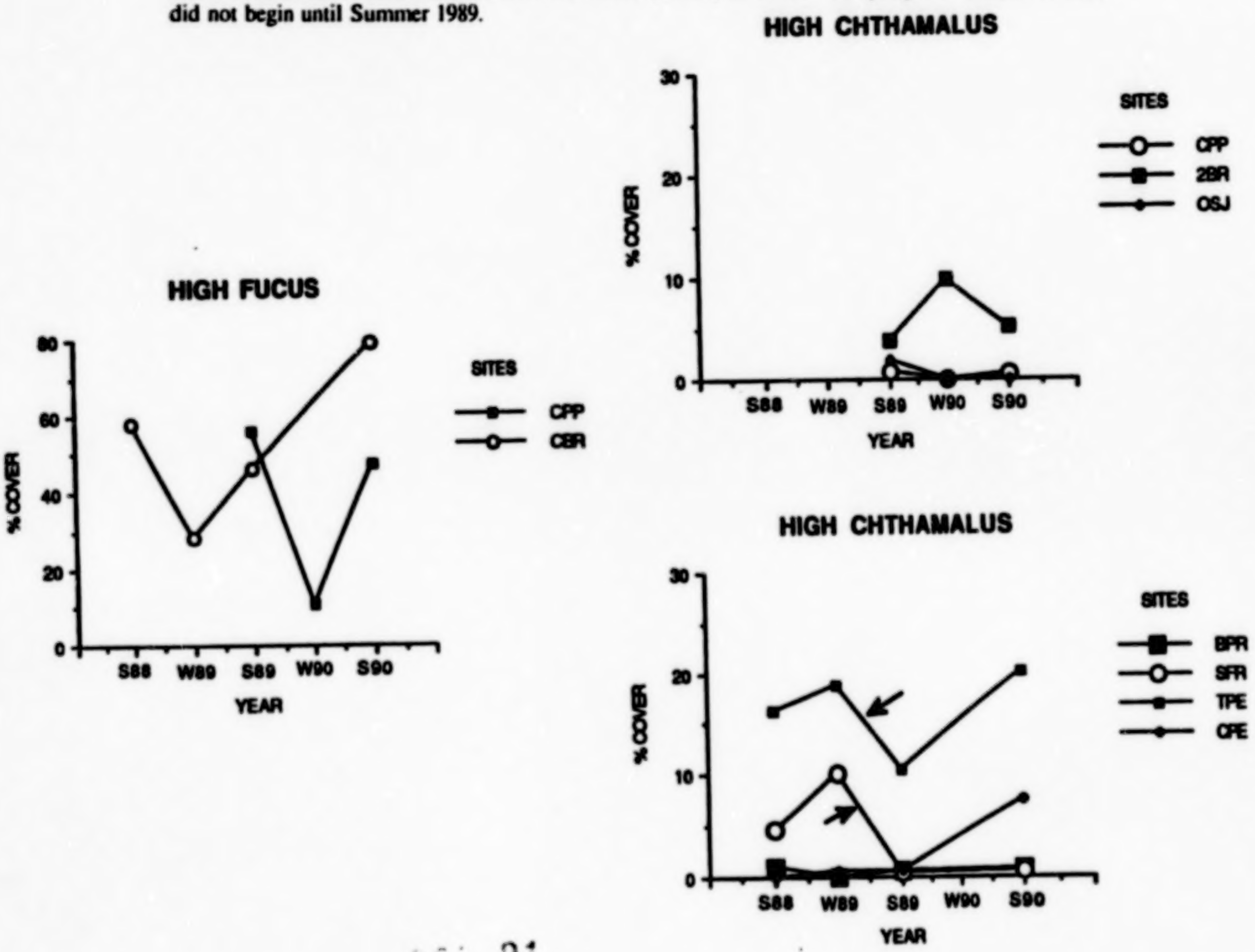


Figure 8. Seasonal and freeze-induced changes in organismal abundance in High rocky quadrats. S88 = summer 1988 sampling, W89 = winter 1989, etc. Site code names are: BPR= Brown's Point, SFR= Starfish Point, TPE= Taylor Point exposed, CPE= Chilean Point exposed, CPP= Chilean Point protected, CBR= Cannonball Island, 2BR= Second Beach, OSJ= Ocean Shores Jetty. Arrows indicate the time of the Feb. 1989 freeze relative to the sampling date: the winter 1989 sampling date was before the freeze (Jan.) at some sites some sites, and after the freeze (March) at others. Sampling at a number of sites did not begin until Summer 1989.

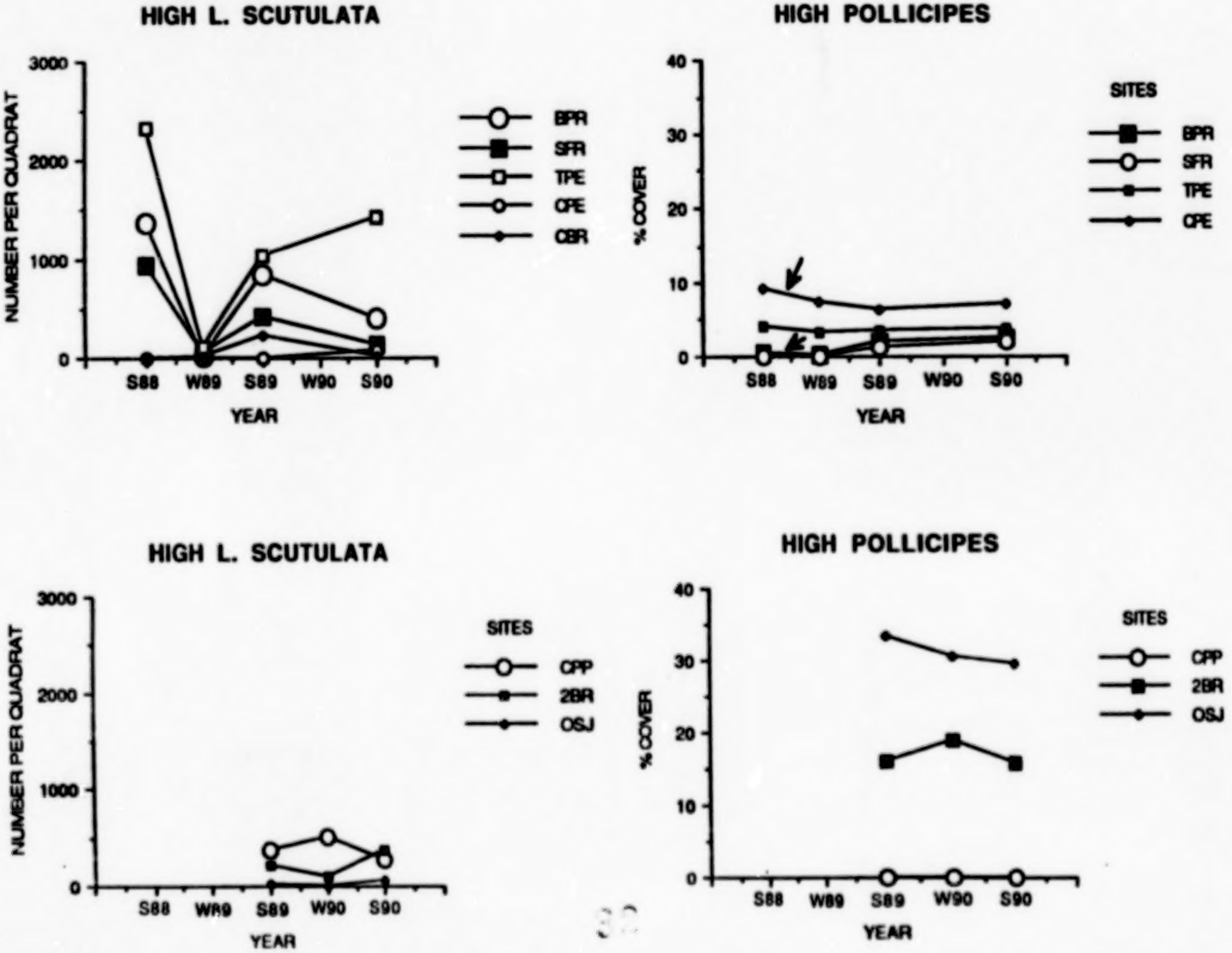
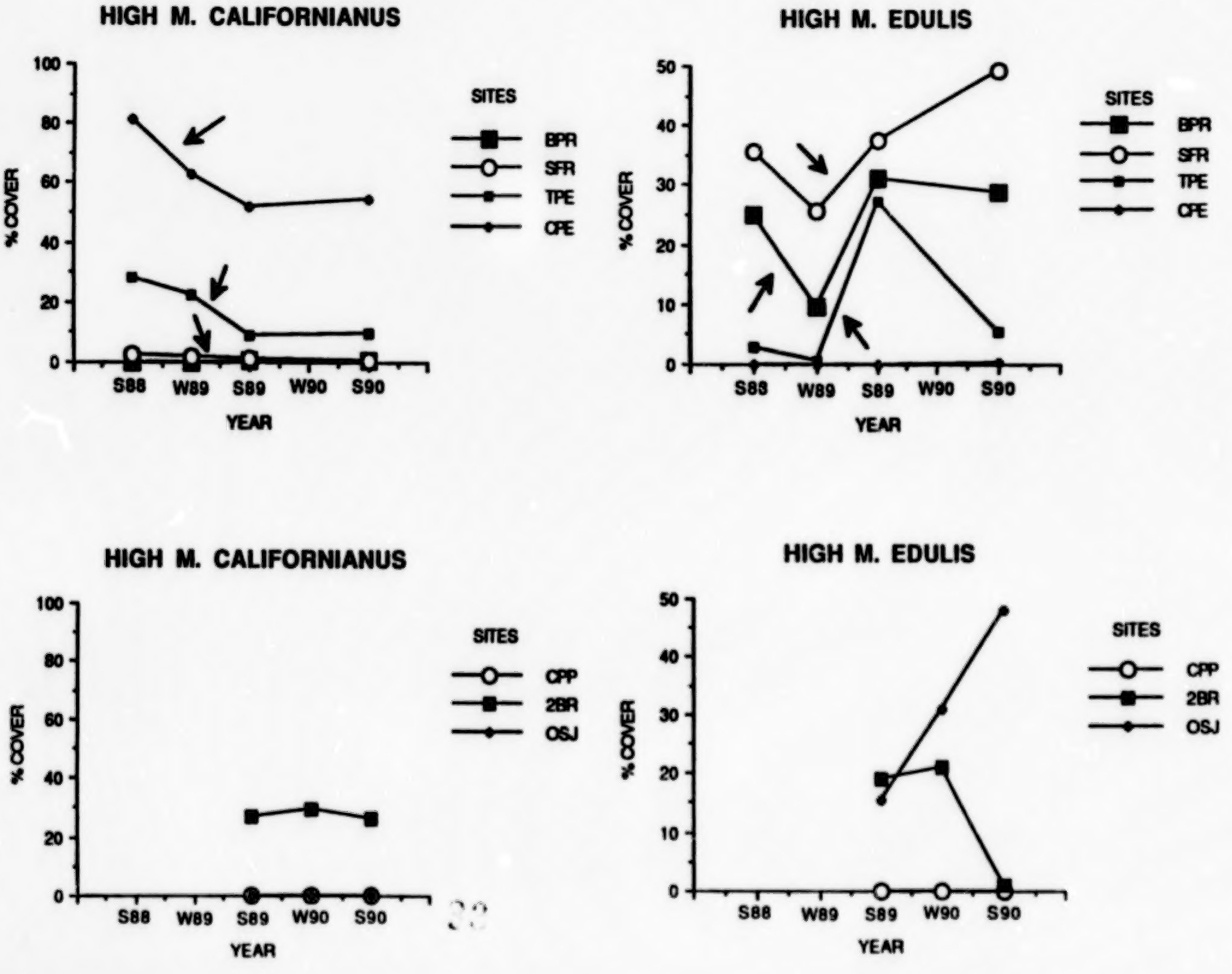


Figure 9. Seasonal and freeze-induced changes in organismal abundance in High rocky quadrats. S88 = summer 1988 sampling, W89 = winter 1989, etc. Site code names are: BPR= Brown's Point, SFR= Starfish Point, TPE= Taylor Point exposed, CPE= Chilean Point exposed, CPP= Chilean Point protected, CBR= Cannonball Island, 2BR= Second Beach, OSJ= Ocean Shores Jetty. Arrows indicate the time of the Feb. 1989 freeze relative to the sampling date: the winter 1989 sampling date was before the freeze (Jan.) at some sites some sites, and after the freeze (March) at others. Sampling at a number of sites did not begin until Summer 1989.


HIGH M. CALIFORNIANUS

HIGH M. EDULIS

HIGH M. CALIFORNIANUS

HIGH M. EDULIS

Figure 10. Seasonal and freeze-induced changes in organismal abundance in High rocky quadrats. S88 = summer 1988 sampling, W89 = winter 1989, etc. Site code names are: BPR= Brown's Point, SFR= Starfish Point, TPE= Taylor Point exposed, CPE= Chilean Point exposed, CPP= Chilean Point protected, CBR= Cannonball Island, 2BR= Second Beach, OSJ= Ocean Shores Jetty. Arrows indicate the time of the Feb. 1989 freeze relative to the sampling date: the winter 1989 sampling date was before the freeze (Jan.) at some sites some sites, and after the freeze (March) at others. Sampling at a number of sites did not begin until Summer 1989.

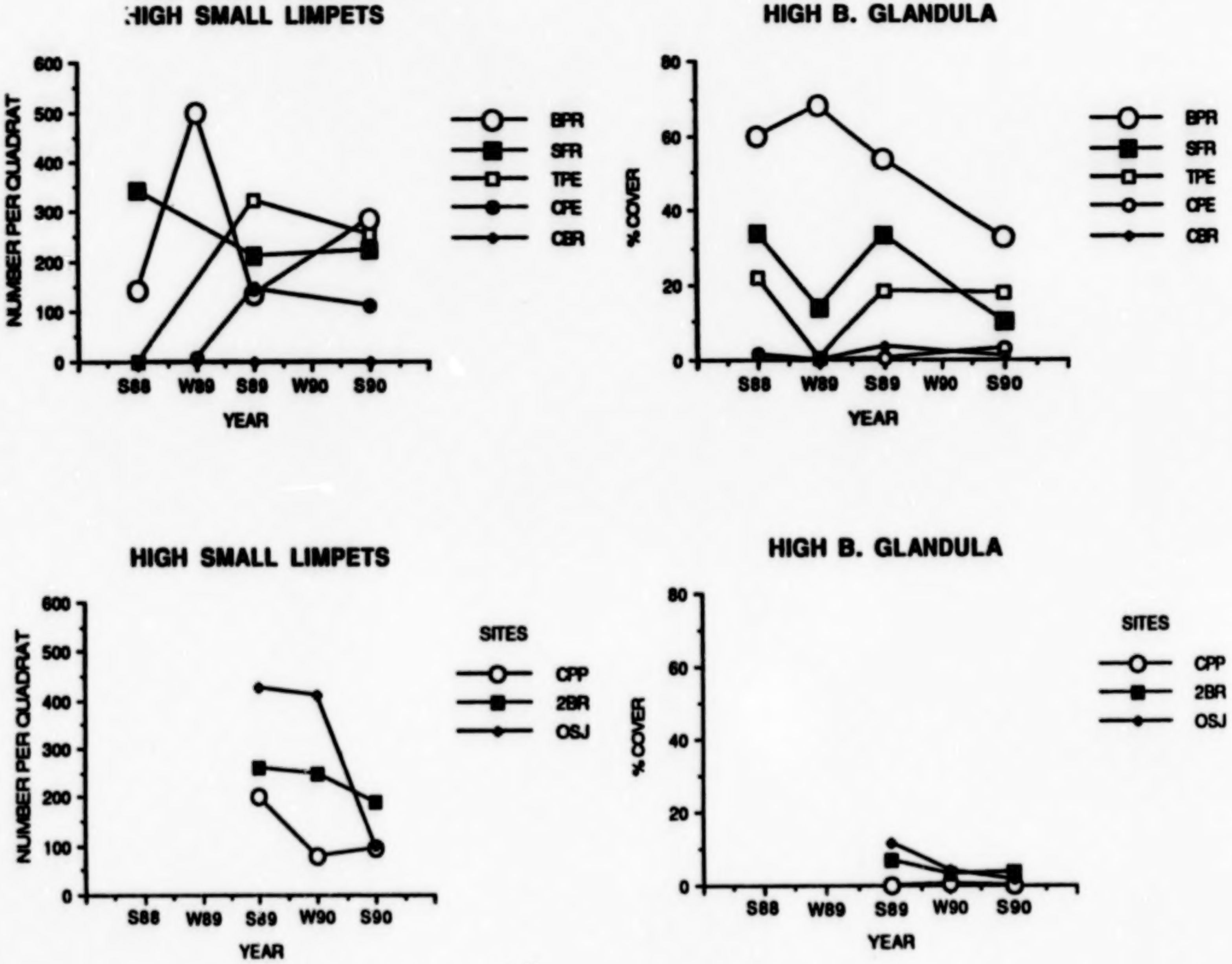
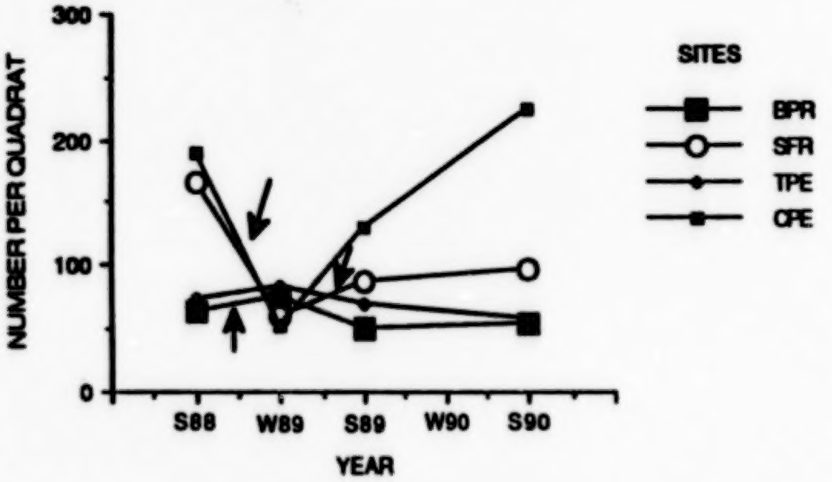


Figure 11. Seasonal and freeze-induced changes in organismal abundance in High rocky quadrats. S88 = summer 1988 sampling, W89 = winter 1989, etc. Site code names are: BPR= Brown's Point, SFR= Starfish Point, TPE= Taylor Point exposed, CPE= Chilean Point exposed, CPP= Chilean Point protected, CBR= Cannonball Island, 2BR= Second Beach, OSJ= Ocean Shores Jetty. Arrows indicate the time of the Feb. 1989 freeze relative to the sampling date: the winter 1989 sampling date was before the freeze (Jan.) at some sites some sites, and after the freeze (March) at others. Sampling at a number of sites did not begin until Summer 1989.

HIGH LIMPETS (ADULT)



HIGH LIMPETS (ADULT)

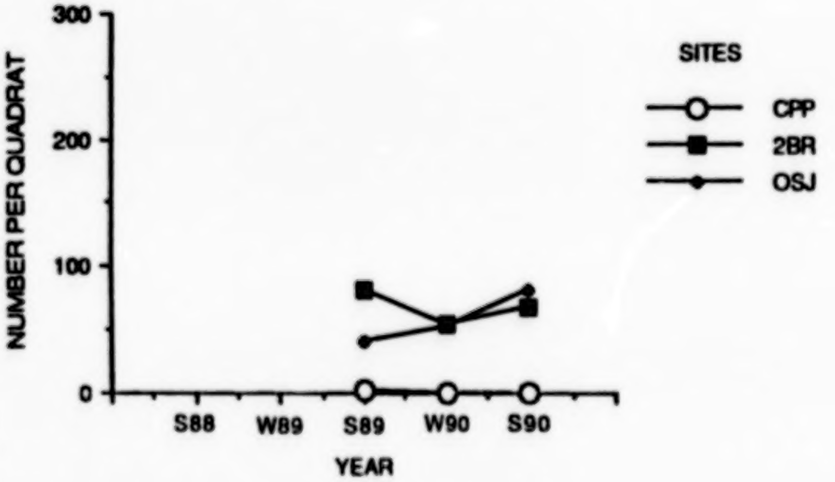


Figure 12. Seasonal changes in organismal abundance in Mid rocky quadrats. S88 = summer 1988 sampling, W89 = winter 1989, etc. Site code names are: BPR= Brown's Point, SFR= Starfish Point, TPE= Taylor Point exposed, CPE= Chilean Point exposed, CPP= Chilean Point protected, CBR= Cannonball Island, 2BR= Second Beach, OSJ= Ocean Shores Jetty. Sampling at a number of sites did not begin until Summer 1989.

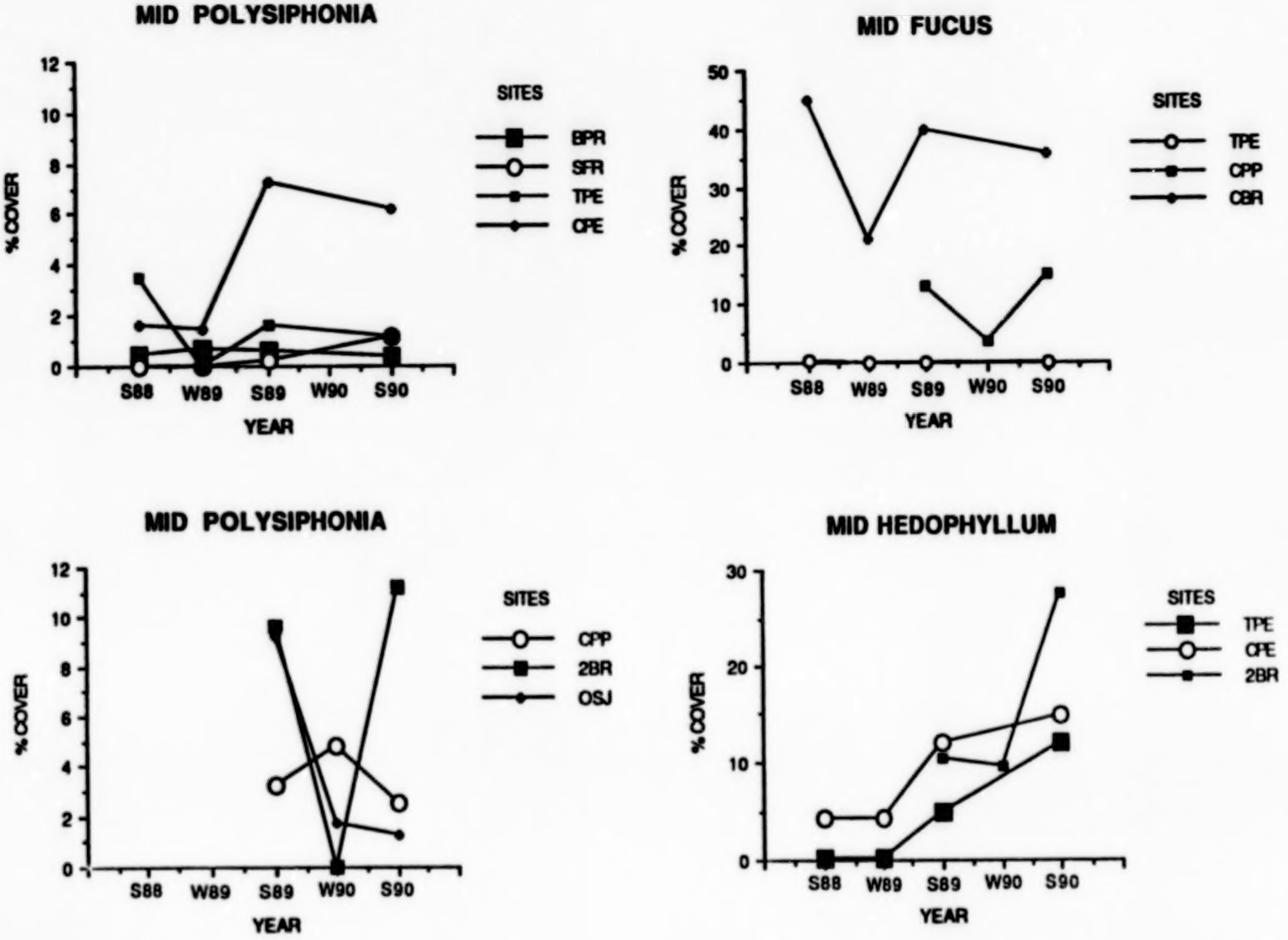


Figure 13. Seasonal changes in organismal abundance in Mid rocky quadrats. S88 = summer 1988 sampling, W89 = winter 1989, etc. Site code names are: BPR= Brown's Point, SFR= Starfish Point, TPE= Taylor Point exposed, CPE= Chilean Point exposed, CPP= Chilean Point protected, CBR= Cannonball Island, 2BR= Second Beach, OSJ= Ocean Shores Jetty. Sampling at a number of sites did not begin until Summer 1989.

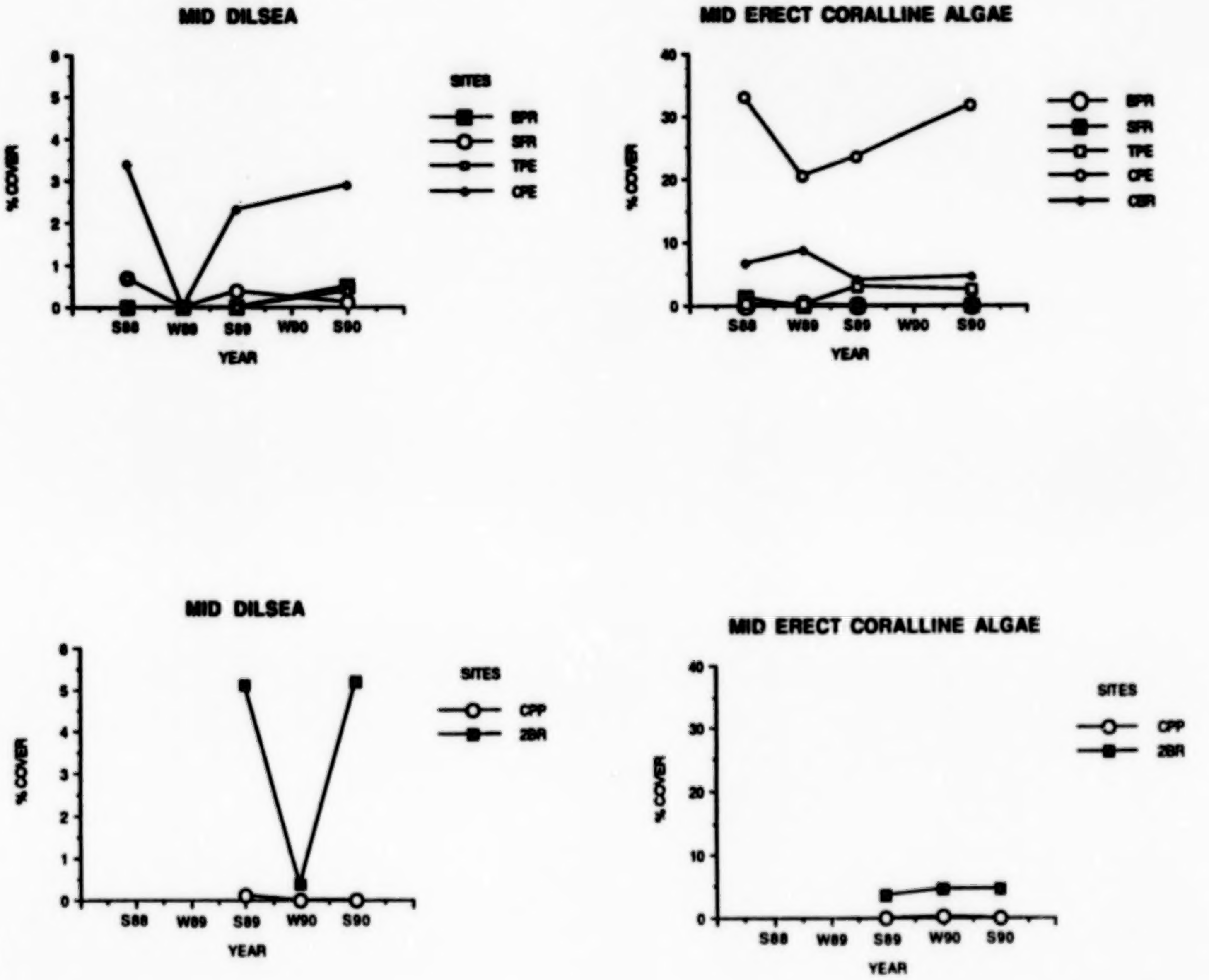


Figure 14. Seasonal changes in organismal abundance in Mid rocky quadrats. S88 = summer 1988 sampling, W89 = winter 1989, etc. Site code names are: BPR= Brown's Point, SFR= Starfish Point, TPE= Taylor Point exposed, CPE= Chilean Point exposed, CPP= Chilean Point protected, CBR= Cannonball Island, 2BR= Second Beach, OSJ= Ocean Shores Jetty. Sampling at a number of sites did not begin until Summer 1989.

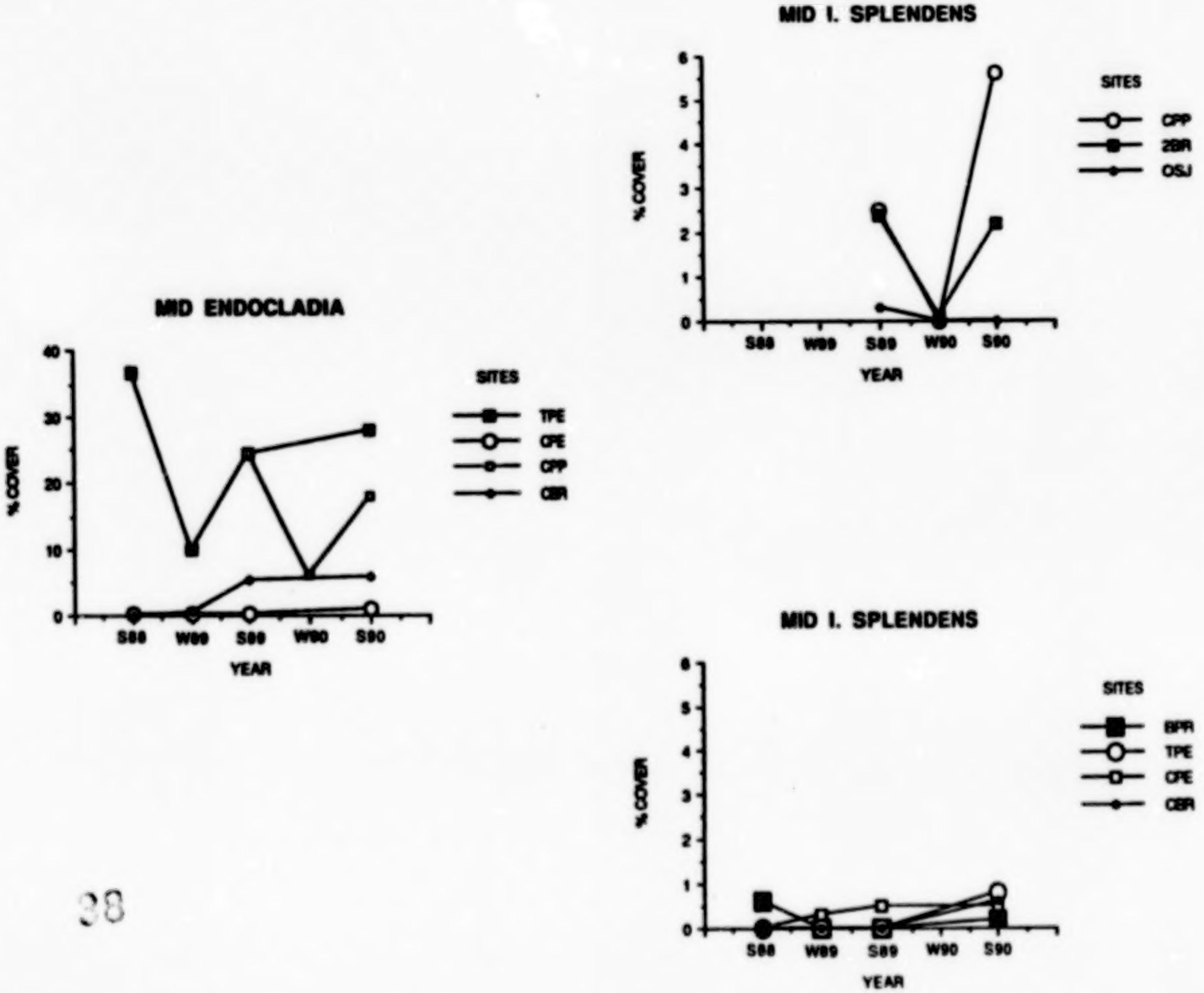


Figure 15. Seasonal changes in organismal abundance in Mid rocky quadrats. S88 = summer 1988 sampling, W89 = winter 1989, etc. Site code names are: BPR= Brown's Point, SFR= Starfish Point, TPE= Taylor Point exposed, CPE= Chilean Point exposed, CPP= Chilean Point protected, CBR= Cannonball Island, 2BR= Second Beach, OSJ= Ocean Shores Jetty. Sampling at a number of sites did not begin until Summer 1989.

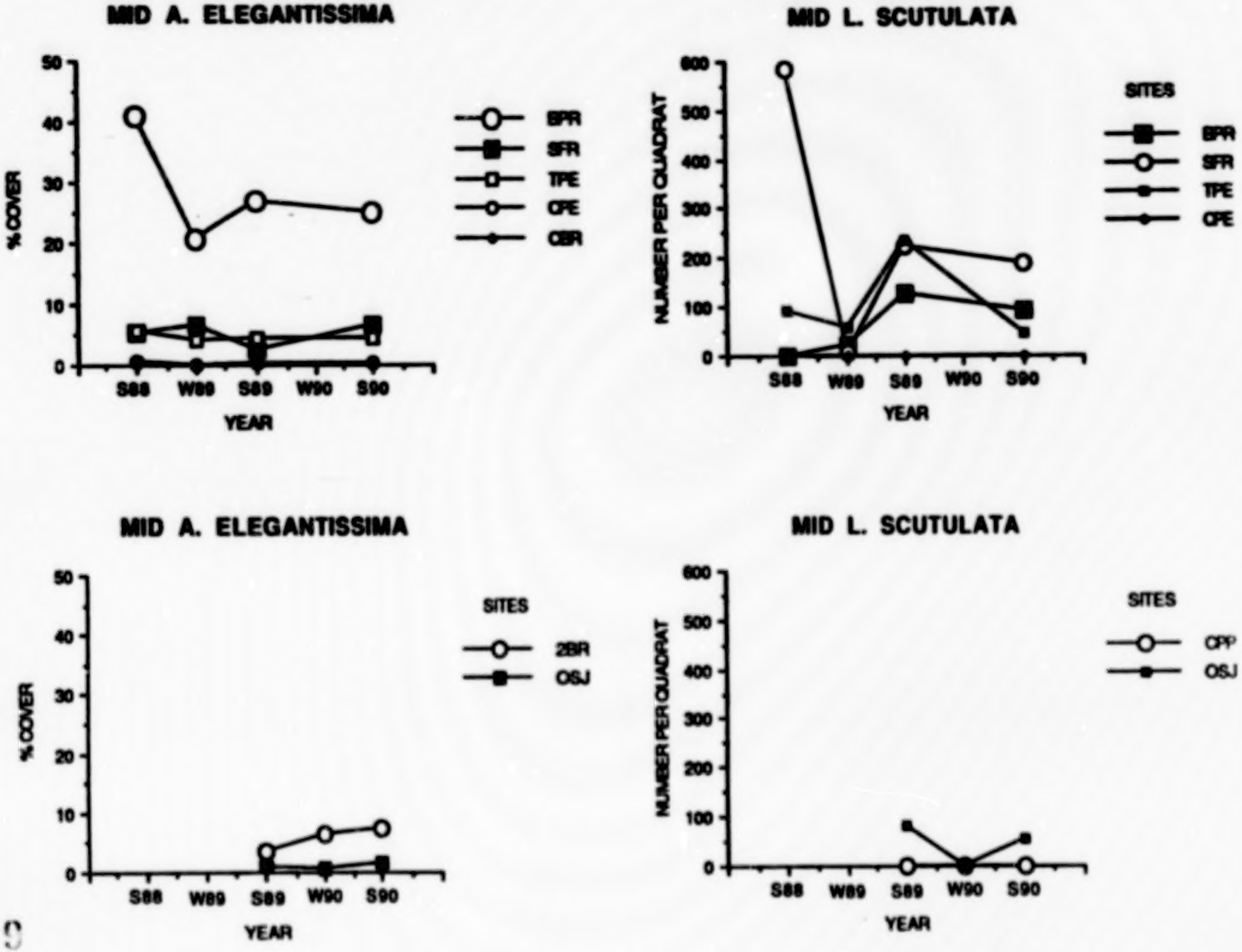


Figure 16. Seasonal changes in organismal abundance in Low rocky quadrats. S88 = summer 1988 sampling, W89 = winter 1989, etc. Site code names are: BPR= Brown's Point, SFR= Starfish Point, TPE= Taylor Point exposed, CPE= Chilean Point exposed, CPP= Chilean Point protected, CBR= Cannonball Island, 2BR= Second Beach, OSJ= Ocean Shores Jetty. Sampling at a number of sites did not begin until Summer 1989.

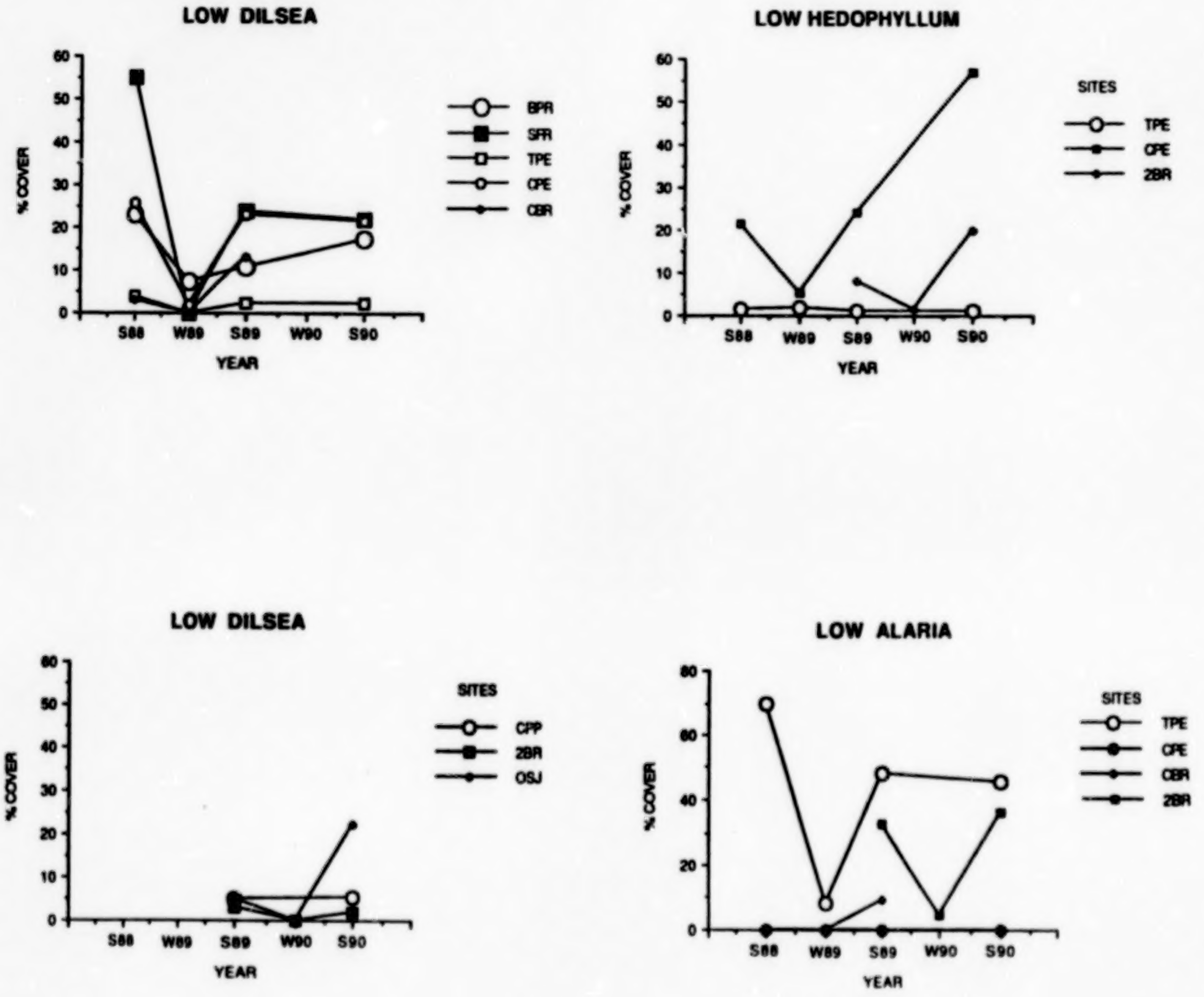


Figure 17. Seasonal changes in organismal abundance in Low rocky quadrats. S88 = summer 1988 sampling, W89 = winter 1989, etc. Site code names are: BPR= Brown's Point, SFR= Starfish Point, TPE= Taylor Point exposed, CPE= Chilean Point exposed, CPP= Chilean Point protected, CBR= Cannonball Island, 2BR= Second Beach, OSJ= Ocean Shores Jetty. Sampling at a number of sites did not begin until Summer 1989.

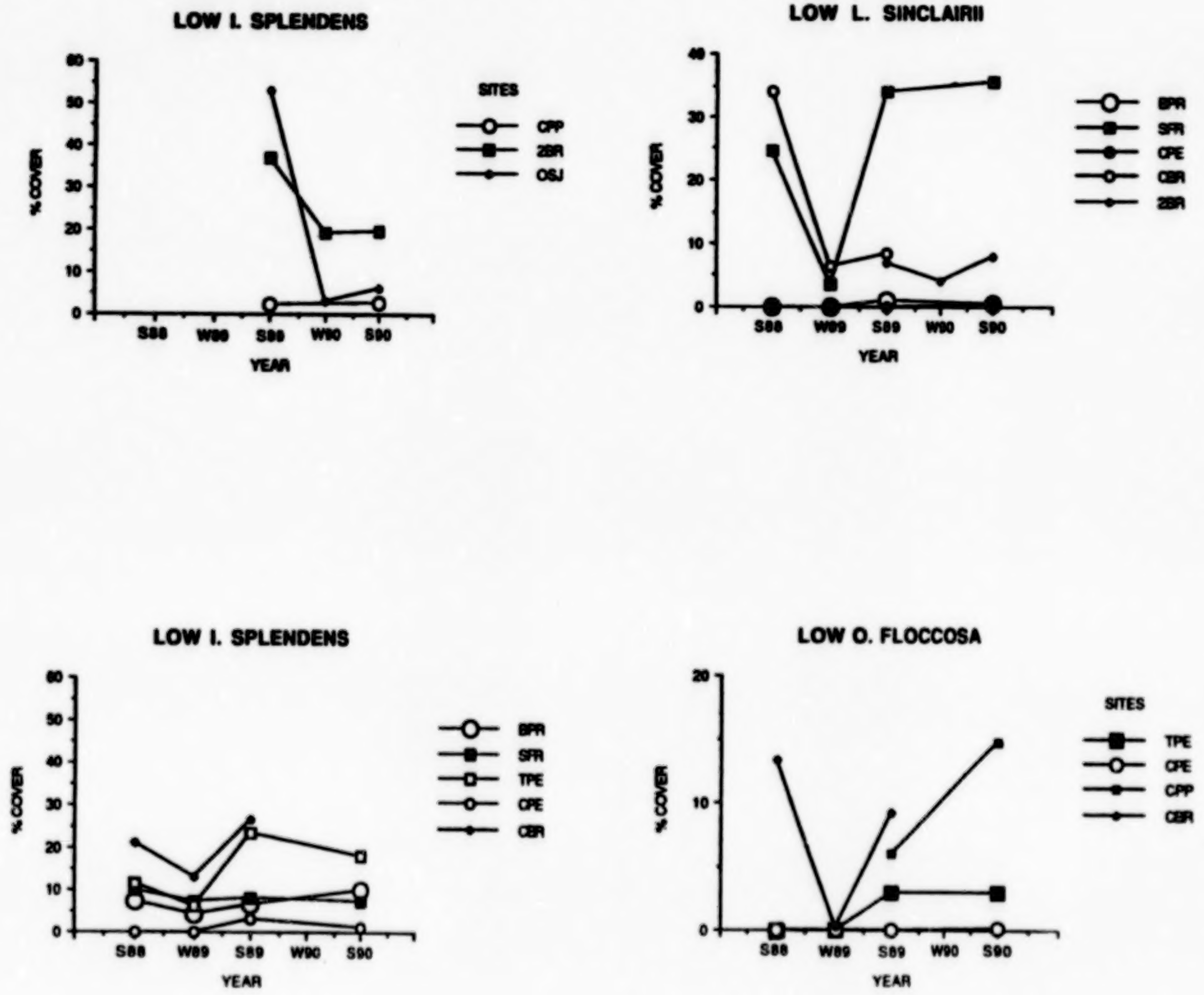
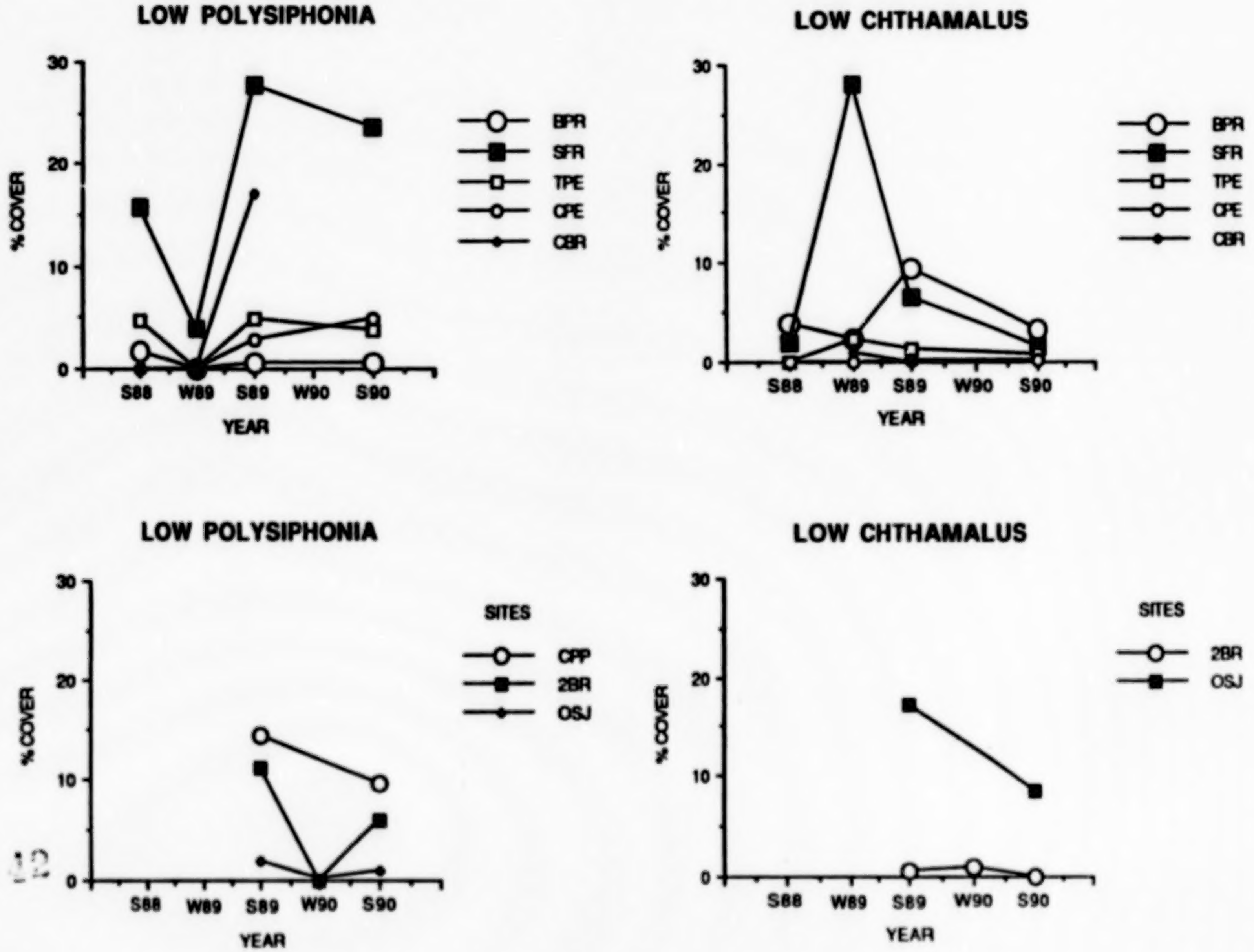


Figure 18. Seasonal changes in organismal abundance in Low rocky quadrats. S88 = summer 1988 sampling, W89 = winter 1989, etc. Site code names are: BPR= Brown's Point, SFR= Starfish Point, TPE= Taylor Point exposed, CPE= Chilean Point exposed, CPP= Chilean Point protected, CBR= Cannonball Island, 2BR= Second Beach, OSJ= Ocean Shores Jetty. Sampling at a number of sites did not begin until Summer 1989.



4.2.8 Impacts of the February 1989 Freeze

From February 1-6, 1989, an extremely cold arctic air mass moved into Washington from Alaska, accompanied by gale-force northeast winds. Temperatures on the coast remained below freezing for about a week, through a spring tide series, and were below 10 degrees Farenheit for several days. Winds exceeded 40 knots for much of this time. The effect on the intertidal zone of this cold spell was severe, especially on higher levels of the shore.

The most obvious organisms to suffer were the California mussels. When we visited permanent sites a month after this freeze, there were still dead, gaping (rotting) mussels attached to the rock, and there were huge windrows of mussel shells that had already been detached and thrown up into pools and onto the beach. The uppermost mussels were clearly hit the hardest; estimates from our sites and from Tatoosh Island (R.T. Paine, pers. comm.) are that at least the upper 1 vertical foot of mussel bed was completely destroyed, leaving bare space with byssus threads attached. The mechanism of death could either have been the cold per se or the extreme desiccation that accompanies dry, cold north winds. Observations on Tatoosh suggested that the mussels on north faces, where spray formed a solid cover of ice over the mussel beds, may have fared better under this insulating coating that those on south faces, which suffered the same temperatures and dry air but did not get iced over.

Figure 9 illustrates the mussel losses in the permanent transects (arrows indicate the time of the freeze relative to our winter sampling period; some sites were sampled before, and others after the freeze). Only at Chilean Point Exposed (CPE) did the High quadrats encompass the upper edge of the mussel bed, and this site showed the most dramatic loss. Three of the six quadrats here had 80-95% cover of multilayered mussels before the freeze, whereas by the following summer, when all the dead mussels had washed away, cover was only 15-45%, and consisted of a monolayer of mussels. Presumably these mussels had been living underneath some of their conspecifics in multilayered beds and received some protection from the freeze. At Taylor Point (TPE), most of the mussel bed is above the high quadrats, but even these lower mussels suffered significant losses (Fig. 9). At Brown's Point (BPR) and Starfish Point (SFR), most of the mussels were in the meter between the High and the Mid quadrats, so little impact was seen in the data. No pre-freeze data were available for Second Beach (2BR) or Ocean Shores (OSJ), although the presence of byssus on the rock in some high quadrats in Summer 1989 suggests that there may have been losses here, too. Other species clearly suffered at these sites (see below).

The Very High quadrats, which are exposed to the air for the longest period, were the hardest hit in terms of number of populations suffering losses at the time of the freeze. Many algal species declined dramatically. The dominant very high alga at Taylor Point (TPE) was *Fucus gardneri*, and it lost a large proportion of its cover (Fig. 2). *Iridaea cornucopiae* dominated at Chilean Point, and showed similar losses (Fig. 2), although in some areas the tips were killed while the regenerative bses remained alive. No data were available from Very High quadrats pre-freeze at Brown's Point, but the steady increases in *Iridaea* (Fig. 2) and in *Endocladia* (Fig. 3) over the next year suggests that these algae may have suffered there, too. At Second Beach, evidence indicates that the upright thalli of *Iridaea* were killed off; at the first sampling (summer 1989) these were only 10 mm long in most quadrats, whereas in winter 1990 they were 10-15, and in summer 1990 they were 15-20 mm long. Thus even this very hardy, very high shore species was impacted by the freeze. *Fucus* at this site similarly grew from 20-30 mm (Summer 1989) up to 50 mm (Summer 1990). Less abundant algae that showed susceptibility to the freeze were *Endocladia* (Fig. 3), *Callithamnion pikeanum*, and *Analipus japonicus* at Chilean Point, and the latter two species at Starfish Point.

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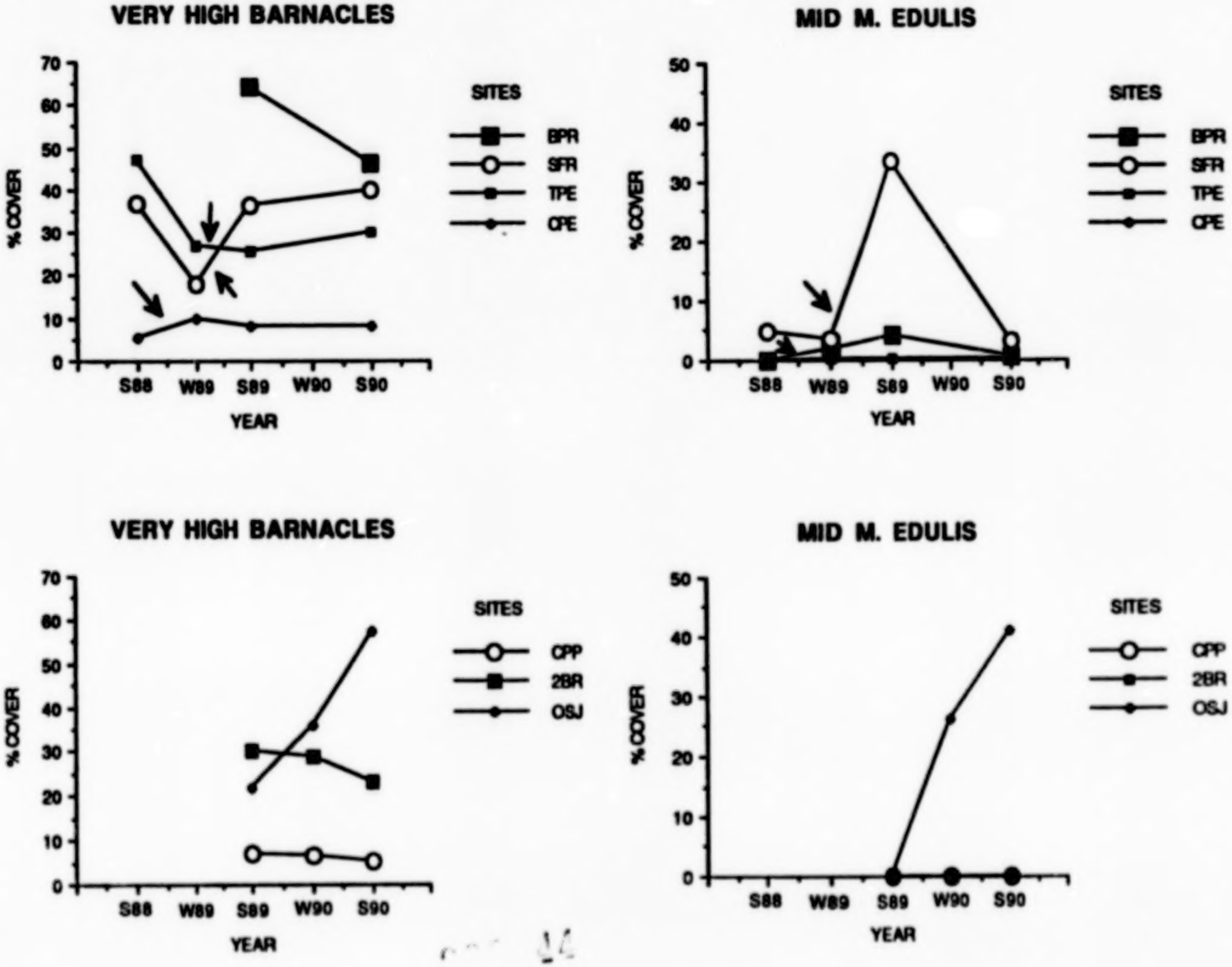
Figure 19. Freeze impact in species not graphed in Figures 2-18. S88 = summer 1988 sampling, W89 = winter 1989, etc. Site code names are: BPR= Brown's Point, SFR= Starfish Point, TPE= Taylor Point exposed, CPE= Chilean Point exposed, CPP= Chilean Point protected, CBR= Cannonball Island, 2BR= Second Beach, OSJ= Ocean Shores Jetty. Sampling at a number of sites did not begin until Summer 1989. Arrows indicate time of freeze relative to winter sampling date.



The animals in the Very High quadrats were less clearly affected. Mytilus edulis declined at all sites except Starfish Point (Fig. 5), although this change is confounded by possible seasonal declines in this species. Limpets were not consistently affected. Barnacles (mostly Balanus glandula at this level) were not clearly affected, although the steady post-freeze increase in barnacle cover at Ocean Shores (Fig. 19) suggests that they were responding to space lost by some organisms during the freeze.

Organisms in the High quadrats predictably did not suffer as much from the freeze. No algae showed obvious freeze damage at this level, perhaps in part because this tends to be an animal-dominated zone. Mytilus edulis declined at one site but not the others, although the later large increase in this mussel at Ocean Shores suggests that many may have been lost there in the freeze, too (Fig. 9). Gooseneck barnacles seemed largely unaffected (Fig. 8), although a few dead ones were seen in the sampling shortly after the freeze. Chthamalus declined sharply at two sites after the freeze (Fig. 7), but this species is notoriously variable in abundance. Other barnacles, limpets, and littorinid snails varied, but none clearly in response to the freeze.

Two types of freeze impact were seen in the Mid quadrats, but only at Chilean Point (one of the hardest-hit sites overall). First, much of the erect coralline algae (mostly Corallina) was observed to be white in March 1989, and had lost up to 30% cover in the quadrats by July. However, the coverage had mostly returned by July 1990, presumably because the encrusting bases survived the freeze and resprouted new uprights. Mytilus californianus also suffered losses at this level, although there were few mussels in these quadrats at any time. All 6 quadrats showed a decline in mussel coverage from Summer 1989 to Summer 1990 (avg. of 5.2 down to 2.9%). Mytilus edulis did not appear to suffer at this height, although again at Ocean Shores there was a dramatic increase in the period after the freeze (Fig. 19), suggesting that much space was opened up (by losses of mussels or other organisms) during the freeze.

Since Mytilus californianus recruits very slowly and only to specific substratum types (Paine and Levin 1981, Suchanek 1986, Paine 1989), it is not surprising that no recovery of these beds was seen over the following year. In fact, Paine (pers. comm.) believes it may be over 20 years before the high mussel beds reestablish, especially because their growth rates at the upper edge of their intertidal range are likely to be very slow. Recovery of other organisms, such as the "weedy" mussels M. edulis, regularly-recruiting barnacles and Fucus, and algae that can regrow from resistant basal portions (such as Iridaea and Analipus), should be relatively rapid.

4.2.9 Impacts of the Oil Spill

The Summer 1989 survey data were examined in detail for oil effects on organisms, comparing "oiled" and "unoiled" sites (see Table 1). Analyses were first run on all 9 rocky sites, but the lumping of protected with exposed sites led to uniformly significant Site effects, obscuring Treatment effects. Thus the 3 protected sites (none of which were visibly oiled) were omitted from subsequent analyses. We ran nested ANOVAs (see Statistical Analyses) on the common species at each tidal height, as well as on certain lumped groups of taxa. These groupings were as follows: Foliose Reds = summed coverage of any non-calcified erect algae; Crusts = summed coverage of all encrusting algae except lichens; Weedy Algae = annual or opportunistic species, such as ulvoids, Polysiphonia, or Halosaccion; Algal Canopy = summed coverage of all erect algae and surfgrass; Barnacles = all acorn barnacles; Herbivores = all limpets, chitons, and herbivorous snails; Mussels == M. californianus and M. edulis; Carnivores = seastars and Nucella. We tested 15 species and 5 groupings for the Very High quadrats, 23 species and 6 groupings for High, 40 species and 6 groupings for Mid, and 40 species and 9 groupings for Low.

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Table 6. Mean and one standard deviation abundances of plants and animals in the **Very High** quadrats at the wave-exposed rocky sites, summer 1989 data. Only rare species are excluded. * = p<.01 significance level from nested ANOVAs, with protected areas excluded, for site effect (S) and treatment (oil) effect (T). OSJ= Ocean Shores Jetty, 2BR= Second Beach, BPR= Brown's Point, SFR= Starfish Point, TPE= Taylor Point exposed, and CPE= Chilean Point exposed.

	OILED		UNOILED				Statistics	
	OSJ	2BR	BPR	SFR	TPE	CPE	S	T
Fucus	0.	7.0 (6.0)	1.9 (1.9)	1.2 (1.6)	5.0 (3.2)	0.8 (0.9)	*	
Endocladia	0.	0.6 (0.8)	4.6 (4.6)	1.4 (1.1)	1.0 (1.1)	2.4 (1.7)		*
Iridaea	0.	21.8 (23.1)	1.8 (2.5)	2.1 (2.0)	0.	16.3 (9.1)	*	
Mastocarpus	0.	0.3 (0.3)	3.3 (4.9)	0.6 (0.2)	0.2 (0.3)	0.3 (0.3)	*	
"Petrocelis"	0.3 (0.3)	2.8 (4.1)	0.6 (0.4)	0.7 (0.3)	0.5 (0)	0.3 (0.3)		
Hildenbrandia	0.1 (0.2)	3.3 (4.1)	1.5 (1.5)	3.5 (4.3)	0.8 (0.3)	21.7 (12.2)	*	*
Arthopyrenia	0.	0.4 (0.5)	0.	0.	0.1 (0.2)	7.8 (11.5)		
Bare	77.6 (8.1)	24.6 (35.9)	7.2 (4.6)	17.2 (21.6)	49.0 (24.6)	12.8 (12.9)	*	*
Emplectonema	0.	0.	10.0 (7.6)	0.	0.2 (0.4)	0.	*	*
M. edulis	0.5 (0)	0.4 (0.2)	12.0 (7.0)	22.2 (15.0)	12.6 (12.0)	7.4 (9.8)		*
Balanus	20.0 (7.9)	30.4 (13.4)	64.0 (15.6)	36.0 (11.9)	25.4 (11.7)	6.2 (4.3)	*	
Chthamalus	0.4 (0.2)	0.6 (0.2)	1.8 (2.4)	2.2 (2.7)	1.6 (0.9)	0.4 (0.2)		
Littorina	111. (83)	380. (202)	1270. (926)	280. (202)	1060. (665)	90. (124)	*	
L. pelta	0.	0.	0.4 (0.9)	3.4 (2.4)	2.6 (3.7)	1.2 (2.0)		
L. strigatella & digitalis	225.0 (91.9)	74.0 (73.8)	73.0 (27.7)	95.0 (44.7)	94.0 (26.1)	145.8 (84.3)	*	
Juvenile limpets	250. (180)	8 (8)	300. (117)	310. (178)	61. (61)	143. (158)		
Foliose reds	0.	22.7 (23.2)	9.7 (10.1)	4.1 (2.8)	1.2 (1.0)	19.1 (9.0)	*	
Crusts	0.4 (0.4)	6.5 (6.2)	2.1 (1.8)	4.2 (4.3)	1.4 (0.4)	29.8 (19.5)	*	
Barnacles	20.4 (7.8)	31.0 (13.5)	65.8 (16.5)	38.2 (12.9)	27.0 (12.1)	6.0 (4.4)	*	
Herbivores	586. (130)	462. (163)	1643. (838)	688. (266)	1217. (647)	380. (96)	*	*
Algal canopy	0.	26.8 (29.7)	11.6 (9.9)	5.3 (3.7)	6.2 (3.2)	19.8 (8.9)	*	

Table 7. Mean and one standard deviation abundances of plants and animals in the **High** quadrats at the wave-exposed rocky sites, summer 1989 data. Only rare species are excluded. * = p<.01 significance level from nested ANOVAs, with protected areas excluded, for site effect (S) and treatment (oil) effect (T). OSJ= Ocean Shores, 2BR= Second Beach, BPR= Brown's Point, SFR= Starfish Point, TPE= Taylor Point exposed, and CPE= Chilean Point exposed.

	Oiled		Unoiled				Statistics	
	OSJ	2BR	BPR	SFR	TPE	CPE	S	T
Fucus	0.	0.	0.	0.1 (0.2)	0.1 (0.2)	0.		
Cladophora	0.2 (0.4)	0.	0.	0.	0.	0.		
Endocladia	0.	0.	0.	0.	4.1 (2.2)	0.8 (1.2)	*	*
Ralfsia	0.	0.4 (.22)	0.3 (0.3)	1.1 (1.1)	1.4 (2)	0.9 (1.1)		*
Hildenbrandia	0.1 (0.2)	1.5 (2.5)	0.3 (0.3)	0.5 (0)	0.3 (0.3)	0.8 (0.7)		
"Petrocelis"	0.	0.4 (.22)	0.2 (0.3)	0.3 (0.4)	0.3 (0.4)	0.2 (0.3)		
Bare	16. (9.6)	2.8 (4.4)	2.8 (4.1)	6.6 (5.7)	14. (16.4)	36.2 (38.7)		
Emplectonema	0.	0.4 (0.9)	11.2 (3.8)	0.2 (0.4)	0.4 (0.9)	0.	*	*
Littorina	22 .(19)	220. (236)	840. (147)	430. (323)	1035. (1019)	0.	*	
N. emarginata	18. (19.6)	22.6 (18.4)	9.2 (11.9)	10.4 (5.5)	29. (35.7)	2.3 (1.6)		
M. californianus	0.	28.9 (28.8)	0	0.	9. (10.2)	51.7 (31.2)	*	
M. edulis	15.2 (12.9)	21.2 (19.9)	31. (11.4)	37.6 (27.4)	27.2 (33.5)	0.	*	
Idotea	0.	0.2 (0.4)	0	0.	0.2 (0.5)	0.		
Semibalanus	31.6 (14.7)	7.3 (7.1)	2.5 (1.9)	4.8 (5.9)	2.8 (3)	2.2 (2.3)	*	*
Balanus	10.8 (10.7)	7.1 (12.8)	54. (10.8)	33.2 (22.8)	18.7 (16.1)	0.75 (1.6)	*	*
Chthamalus	1.3 (2.6)	3.6 (1.1)	0.6 (0.4)	0.3 (0.3)	10.4 (4.5)	0.6 (0.4)	*	
Pollicipes	33.3 (19.7)	16.1 (19.6)	2. (3.4)	1.2 (2.1)	3.5 (4.4)	6.4 (6.3)		*
L. pelta	0.	5.6 (8.3)	0.8 (1.8)	0.	5.4 (3.80	1.2 (1.8)	*	
L. strigatella & digitalis	40. (26)	75. (18)	50. (0)	86. (64)	64. (50)	126. (62)		
Juvenile limpets	426. (244)	260. (164)	135. (42)	210. (108)	324. (298)	145. (759)		

Table 7, cont'd.

	Oiled		Unoiled				Statistics	
	OSJ	2BR	BPR	SFR	TPE	CPE	S	I
Nemerteans	0.	0.4 (0.9)	11.2 (3.8)	2.0 (3.9)	1.0 (1.0)	0.4 (0.9)		
Crusts	0.1 (0.2)	2.3 (2.94)	0.8 (0.3)	1.9 (1.5)	2.0 (2.1)	1.8 (1.2)		*
Barnacles	43.7 (14.1)	18.0 (9.9)	57.1 (9.1)	38.3 (25.2)	31.9 (21.2)	3.5 (4.3)	*	
Mussels	15.4 (13.3)	50.1 (9.6)	31.0 (11.4)	37.6 (27.4)	36.2 (26.0)	51.7 (31.2)		
Herbivores	488. (276)	561. (369)	1025. (138)	726. (409)	1428. (1279)	272. (124)		
Carnivores	18.0 (19.6)	27.0 (18.1)	9.2 (11.9)	10.4 (5.5)	29.0 (35.7)	2.3 (1.6)		
Algal canopy	0.2 (0.4)	0.	0.	0.1 (0.2)	4.2 (2.0)	3.6 (6.0)	*	*

Table 8. Mean and one standard deviation abundances of plants and animals in the **Mid** quadrats at the wave-exposed rocky sites, summer 1989 data. Only rare species are excluded. * = p<.01 significance level from nested ANOVAs, with protected areas excluded, for site effect (S) and treatment (oil) effect (T). OSJ= Ocean Shores, 2BR= Second Beach, BPR= Brown's Point, SFR= Starfish Point, TPE= Taylor Point exposed, and CPE= Chilean Point exposed.

	Oiled		Unoiled				Statistics	
	OSJ	2BR	BPR	SFR	TPE	CPE	S	I
Hedophyllum	0.	10.4 (19.5)	0.	0.	5. (11.2)	7.5 (13.6)		
Dilsea	0.	5.10 (4.77)	0.	0.	0.	2.25 (2.23)		
Ulva	0.	0.1 (0.2)	0.	0.	0.1 (0.2)	0.2 (0.4)		
Microcladia	0.1 (0.2)	5.4 (5.2)	0.	0.1 (0.2)	0.1 (0.2)	5.5 (3.8)	*	
Mastocarpus	0.1 (0.2)	2. (2.8)	0.1 (0.2)	0.	6.6 (5.3)	0.	*	
Endocladia	0.	0.	0.	0.	24.4 (17.4)	0.2 (0.4)	*	
Analipus	0.	0.	0.	0.	1.8 (1.6)	0.1 (0.2)	*	
Polysiphonia	9.2 (11.4)	9.6 (5.1)	0.6 (0.9)	0.2 (0.4)	1.6 (2.6)	8.1 (7.7)		*
Cladophora	0.	0.2 (0.3)	0.	0.	0.1 (0.2)	0.		
Callithamnion	0.	5.6 (5.9)	0.	0.	0.8 (1.8)	1.5 (1.4)	*	
Erect Corallines	0.	3.5 (2.1)	0.	0.	3.2 (6.6)	23.7 (18.3)	*	
Encrusting Corallines	0.	6.2 (8.8)	0.	0.	3.0 (6.7)	1. (2.4)		
Hildenbrandia	0.3 (0.3)	7.2 (3.3)	6.6 (10.9)	0.	8.1 (11.4)	3.8 (3.4)		
Ralfsia	1 (1.1)	3 (2.2)	0.9 (1)	0.1 (0.2)	13. (13.1)	2.6 (2.2)	*	
"Petrocelis"	0.4 (0.2)	4.2 (4.5)	0.	0.	3.8 (4.1)	0.2 (0.3)	*	
Bare	57. (7.6)	8. (17.9)	30.4 (15.7)	3.6 (3.3)	49. (24.6)	6.6 (11.8)		
Balanus	1.2 (1.6)	0.	13.4 (13.3)	10. (19.6)	2.6 (4.3)	0.1 (0.2)		
Semibalanus	8.8 (5.8)	0.1 (0.2)	0.2 (0.4)	8.6 (12.6)	0.	1.2 (2)	*	
Chthamalus	2.7 (3.)	1.8 (1.5)	9.2 (10.)	2.2 (2.3)	21.4 (16)	3. (4.6)	*	
Small barnacles	6. (5.5)	19.6 (7.1)	0.	0.	0.	0.	*	*
Pollicipes	11.7 (7.3)	0.1 (0.2)	0.5 (0.9)	30.2 (18.3)	0.1 (0.2)	3.3 (4.4)	*	
L. pelta	0.	1.8 (2.5)	0.	2.8 (4.4)	7. (4.9)	24.7 (16.4)	*	*
L. strigatella & *digitalis*	82. (48)	0.	0.	21. (12.4)	0.	0.8 (2)	*	*

Table 8, cont'd.

		Oiled			Unoiled		Statistics	
	OSJ	2BR	BPR	SFR	TPE	CPE	S	I
Juvenile limpets	810. (288)	161. (107)	370. (254)	114. (107)	248. (172)	121. (138)		
M. californianus	0.	0.	0.	1.6 (1.1)	0.	3.5 (3.3)	•	•
M. edulis	0.4 (0.2)	0.1 (0.2)	4.2 (5.1)	35. (18.9)	0.2 (0.3)	0.2 (0.4)	•	•
A. elegantissima	1. (0.6)	3.4 (4.9)	27. (31.2)	3.3 (2.5)	4.5 (5)	0.2 (0.3)	•	
A. xanth.	0.	5. (2.4)	2.8 (2.2)	1.5 (1.6)	0.2 (0.4)	0.	•	
Pisaster	0.4 (0.5)	7. (12)	0.6 (0.9)	0.	0.8 (0.8)	0.		
Leptasterias	0.	0.	0.	0.	5.4 (10.5)	1.3 (1.2)		
Nucella	77. (78.4)	0.	0.4 (0.9)	49. (32.1)	0.2 (0.4)	1.3 (1.6)	•	
Littorina	80. (74.4)	0.	128. (65)	226. (224)	235. (355)	0.	•	
Lacuna	0.	5. (11.2)	1. (2.2)	0.	10. (22.4)	0.		
Katharina	0.	1.6 (1.5)	0.2 (0.4)	0.	1.2 (2.5)	8.2 (6.1)	•	
Lepidochiton	0.	2.6 (3.1)	0.	0.	0.	3.4 (4.4)		
Idotea	0.	17. (19.5)	0.	0.	3. (4.5)	1.7 (1.5)	•	
Nemerteans	0.2 (0.4)	0.4 (0.9)	0.4 (0.9)	1.0 (1.0)	0.4 (0.5)	6.6 (11.8)		
Foliose reds	9.7 (11.3)	31.3 (18.2)	0.7 (0.8)	0.2 (0.4)	18.9 (13.8)	24.9 (14.3)	•	•
Weedy algae	0.	6.2 (8.8)	0.	0.	6.6 (7.7)	8.1 (10.1)	•	
Crusts	4.3 (2.2)	16.7 (3.9)	10.5 (11.4)	3.1 (1.4)	30.3 (25.0)	33.5 (14.4)	•	
Barnacles	16.0 (4.2)	19.7 (7.3)	13.6 (13.7)	18.6 (19.1)	2.6 (4.3)	1.3 (1.9)	•	•
Herbivores	1061. (213)	163. (108)	499. (275)	443. (241)	490. (421)	151. (134)	•	
Algal canopy	9.8 (11.2)	43.7 (13.8)	0.7 (0.8)	0.3 (0.4)	49.2 (7.8)	31.3 (11.3)	•	

Table 9. Mean and one standard deviation abundances of plants and animals in the Low quadrats at the wave-exposed rocky sites, summer 1989 data. Only rare species are excluded. * = $p < .01$ significance level from nested ANOVAs, with protected areas excluded, for site effect (S) and treatment (oil) effect (T). OSJ= Ocean Shores, 2BR= Second Beach, BPR= Brown's Point, SFR= Starfish Point, TPE= Taylor Point, and CPE= Chilean Point.

	Oiled		Unoiled				Statistics	
	OSJ	2BR	BPR	SFR	TPE	CPE	S	T
Hedophyllum	0.	8. (17.9)	0.	0.	1.2 (2.7)	24.2 (31.8)	*	
Dilsea	5. (5)	2.9 (3)	10.6 (8.5)	23.8 (24.2)	2.4 (3.3)	23.2 (17.2)		
Microcladia	0.	0.	0.6 (0.9)	1.1 (0.9)	0.1 (0.2)	5.2 (6.5)		*
Polysiphonia	2.1 (4.4)	11.2 (17.2)	0.6 (0.5)	31.8 (31.2)	4.8 (2.3)	2.8 (6.0)	*	
Cryptopleura	0.	0.4 (0.9)	0.	0.	0.9 (1)	19.4 (18.1)	*	
Iridaea	53. (27.6)	37. (20.8)	6.4 (2.6)	8. (4.5)	16.2 (17.6)	3.2 (4.6)		*
Erect Corallines	0.	0.6 (0.4)	2.5 (1.9)	3. (2.4)	7.2 (6.2)	9.8 (7.5)		*
Encrusting Corallines	0.	14.8 (11.9)	14. (14.8)	4. (3.5)	45.2 (32.7)	13.8 (5.3)	*	*
Mastocarpus	0.	0.5 (0.9)	0.1 (0.2)	0.4 (0.9)	3. (3.1)	0.1 (0.2)	*	
Alaria	0.	33. (32.7)	0.	0.	30. (27.6)	0.1 (0.2)	*	
Laminaria	0.	7. (15.7)	1. (2.2)	34.2 (35.1)	0.	0.	*	
Ptiloda	0.	2.2 (2.3)	0.	0.	2.2 (2.3)	0.	*	
Phaeostrophion	0.	0.	0.1 (0.2)	0.2 (0.4)	4.1 (6.9)	0.		
Ralfsia	4.8 (6.1)	1.4 (0.9)	1.1 (1.7)	0.4 (0.9)	2.6 (2.4)	0.8 (1)		
Hildenbrandia	3.2 (3.9)	22. (20.2)	7.8 (5.8)	8. (11.5)	0.4 (0.9)	3.2 (2.2)		
Bare	0.	3.8 (3)	8.2 (9.9)	0.6 (1.3)	0.6 (0.9)	2.6 (3)	*	
Balanus	16.8 (7.8)	0.8 (1.8)	0.	0.7 (0.8)	0.7 (0.8)	0.	*	*
Chthamalus	17.2 (8.8)	0.5 (0.5)	9.5 (8.9)	6.4 (10.4)	0.2 (0.4)	0.2 (0.4)	*	
Lacuna	0.	20. (27)	0.	21. (44)	5. (11)	8.3 (20.4)		
L. pelta	8. (4.5)	0.	0.	7.6 (7.8)	0.4 (0.9)	3.7 (8)	*	
Nucella	3.8 (6.9)	0.	0.4 (0.5)	0.	0.4 (0.9)	0.		
A. xantho.	0.	3.4 (1.7)	4.3 (3.8)	0.5 (0.9)	0.	0.1 (0.2)	*	

Table 9. cont'd.

	Oiled			Unoiled			Statistics	
	OSJ	2BR	BPR	SFR	TPE	CPE	S	I
A. elegan.	0.9 (0.7)	0.	6.7 (5.8)	0.5 (0.9)	0.1 (0.2)	0.	•	
Pisaster	0.	2. (1.9)	1. (1.7)	0.4 (0.5)	0.	0.2 (0.4)		
Leptasterias	0.4 (0.6)	0.	11. (11.4)	22. (17.5)	0.	0.5 (0.5)	•	•
Idotea	1.2 (1.8)	2. (2.7)	1. (2.2)	15. (5)	5.4 (2.7)	0.	•	
Mopalia	2.2 (1.9)	0.4 (0.5)	7.4 (3)	0.8 (1.3)	0.2 (0.4)	0.3 (0.8)	•	
Tonicella	0.	1.8 (2.5)	1.6 (2.2)	0.2 (0.4)	2.6 (2.5)	2.7 (2)		
Katharina	0.	0.2 (0.4)	0.	0.	0.	2.7 (3.9)		
Sabellids	0.	1.4 (1.6)	0.2 (0.4)	5.6 (8.4)	1.2 (1.3)	0.6 (0.5)		
Eudistylia	0.	0.2 (0.3)	6.4 (7)	0.	0.	0.	•	
Alia	0.	2. (4.5)	0.	0.	6. (13.4)	0.		
Juvenile Limpets	300. (288)	6. (6.5)	52. (59)	40. (89)	50. (50)	60.8 (118)		
Kelp	0.	48.0 (32.1)	1.0 (2.2)	34.2 (35.1)	31.2 (28.5)	24.2 (31.8)	•	
Foliose reds	60.1 (27.4)	45.2 (19.9)	18.3 (10.0)	65.1 (37.0)	34.4 (9.6)	53.9 (24.8)		
Weedy algae	2.1 (4.4)	11.2 (17.3)	0.6 (0.5)	31.8 (31.1)	5.0 (2.3)	2.8 (6.0)	•	
Crusts	8.0 (5.9)	38.2 (22.6)	22.9 (11.0)	12.4 (11.7)	48.2 (33.0)	17.8 (4.2)		
Barnacles	34.0 (16.4)	1.3 (1.6)	9.5 (8.9)	7.1 (11.2)	0.9 (1.0)	0.2 (0.4)	•	•
Gastropod herbivores	308. (290)	28. (30)	52. (59)	68.6 (141)	61.4 (59.1)	73. (123)		
Chitons	2.2 (1.9)	2.4 (2.5)	9.0 (4.0)	1.0 (1.7)	2.8 (2.6)	5.7 (5.1)		
Starfish	0.4 (0.6)	2.0 (1.9)	12.0 (11.9)	22.4 (17.3)	0.	0.7 (0.8)	•	•
Algal canopy	60.1 (27.4)	102.8 (16.8)	21.9 (11.8)	102.5 (34.9)	76.9 (29.6)	88.0 (17.6)	•	

Tables 6-9 summarize the mean abundances for these species at the wave-exposed sites and give the significance level of the treatment (oil) and site effects.

Overall, it is very difficult to differentiate between genuine oil impacts, freeze impacts, and simple site-to-site differences that happened to correlate with the oiled vs. unoiled assessment. It should be noted here that by the time of the sampling (June-July 1989), over 6 months after the spill, *no oil* was observed at any of the rocky sites. The Ocean Shores Jetty and the rock at Second Beach were designated as "oiled" because Park Service and Washington Department of Ecology personnel reported that the adjacent beaches, at least, were some of the most heavily oiled areas along the coast; thus it was assumed that the adjacent rocky areas might have been impacted. This assumption may not be accurate; rocky headlands often refract incoming waves (including those bearing oil) so that little oil actually gets brought ashore there. Rather, oil may get funneled into pocket beaches or hit long straight stretches of sandy beach. This appears to have been the case on the coast of Washington, with a few exceptions; some oil did hit cobble benches (discussed below), and one headland north of Norwegian Memorial received substantial oiling, and was subsequently referred to as "Taffy Point" by locals. This site has been studied by the Kinnetics research group, and we did not visit it. The other 4 exposed rocky sites were designated "unoiled", as the adjacent beaches were unoiled or only lightly impacted.

Many of the significant oil effects marked in Tables 6-9 appear to be due to the anomalous nature of the Ocean Shores Jetty, one of the two "oiled" sites. Unfortunately, no pre-oil (or pre-freeze) data are available for either of the oiled sites; none of the sites (rocky or sandy) surveyed in Summer 1988 were oiled substantially. However, the 1989 and 1990 samplings at Ocean Shores all suggested that this site is intrinsically unusual, and not a good comparison to the natural rocky shores. Diversity (see Table 10) and organismal abundance at Ocean Shores Jetty were very low, with the exception of barnacles. Some of the most obvious differences were that the site almost completely lacked the common red crusts *Hildenbrandia* and encrusting corallines, any kelps or other brown algae except for the crust *Ralfsia*, the common red macroalgae *Mastocarpus* and *Endocladia*, and California mussels, all of which were common at the other rocky sites. There are a variety of non-exclusive hypotheses for these absences: 1) the jetty, while made of native rock, has not been present for thousands of years as have the bedrock headlands. Since some algae colonize poorly, and there are no rocky areas within tens of km of the jetty, dispersal and colonization may have been limiting. However, the jetty was built in 1914, and has thus had over 75 years to be colonized. 2) The jetty is at the mouth of the large estuary of Grays Harbor. While we sampled the "outside" of the jetty, away from the estuary, salinities even there are likely to be low and variable, and this may limit some of the organisms. Heavy siltation in the plume from the estuary may also limit some species. 3) Surfaces at the jetty may get scoured, since it is at the end of tens of km of sandy beach and is wave-exposed. On our 3 trips there, visibility in the water column was always very low, probably from a combination of suspended sand, silt, and organics. The jetty did have some aspects in common with the "sand-impacted" rocky areas, such as abundant *Dilsea* low, sandy mats of amphipods on low surfaces, and abundance of small barnacles at most levels. 4) The jetty is used by fishermen for sport fishing, and perhaps also for bait collection. While this could account for the virtual absence of California mussels, the low amount of traffic and the inaccessibility of some of the surveyed surfaces makes it unlikely that this was a key structuring force. 5) The jetty may have less structural heterogeneity than the natural rock because it consists of cuboidal, relatively smooth-faced cut chunks of rock; thus the small and large crevices and holes that may serve as recruitment sites and refuges for plants and animals are few. 6) The jetty was the only rocky site that faced truly north (Table 1), and thus it could have been severely impacted by the freeze before our first sampling. While some species clearly were damaged by the freeze (see above), we doubt that this accounts for all the anomalies. 7) Since Ocean Shores was close to the source of the oil spill, the area including the jetty could have been more impacted by the oil, especially by light, toxic fractions that evaporated before the oil hit other locations. However, no oil was observed on any of the rock surfaces, and it is unlikely that these difficult-to-access sites could have been cleaned that thoroughly. Also, the sand infauna adjacent to the jetty did not suggest an oil effect (see below).

Table 6 shows that in the Very High rocky quadrats, there were significant "treatment" effects in 4 species, 1 grouping, and in Bare space. Two of these effects (in Hildenbrandia and bare space) appear to be due to the anomalous nature of the jetty; Second Beach abundances were close to those of most of the unoiled sites. For two other species (Endocladia and Mytilus edulis), both "oiled" sites showed low abundance. This could be a real oil effect (the morphology of Endocladia makes it likely to "catch" oil), or could be due to the freeze (both species showed possible freeze effects, discussed above, and Ocean Shores and Second Beach were the two most north-facing sites). Due to the temporal proximity of these two events, it is impossible to separate them. The fourth species, the nemertean Emplectonema, was rare at virtually all sites, and the treatment effect is meaningless. The treatment effect seen in herbivore abundance is driven by the high variance in numbers of Littorina spp., which did not by itself show a treatment effect. It is unlikely that this is a meaningful difference, although it is possible that all herbivores could have declined in number due to oil in the water column; molluscs are susceptible to the narcotizing effects of oil.

In the High quadrats, there were significant treatment effects in 6 species and 2 groupings (Table 7). As in the Very High quadrats, Endocladia was significantly less abundant at the "oiled" sites. This could again be either an oil effect or a freeze effect; we consider the latter more likely, because neither the unoiled Starfish Point or Brown's Point, both of which face slightly north, had any Endocladia either. The brown crust Ralfsia showed a significant effect, but the mean abundances were all very low: probably not a meaningful difference. There may be somewhat less at the oiled sites because both had mussels and barnacles dominating the rock at this height, outcompeting crusts. Emplectomena again was different but very patchy among all sites, and we doubt that this difference is an oil effect. Balanus glandula was similarly very patchy among sites. Two other barnacles, Semibalanus cariosus and Pollicipes, were actually more abundant at the "oiled" sites, which is very likely to be a spurious correlation. The High quadrats at the two oiled sites happened to be in the middle of the zones of these barnacles, leading to high abundances. Grouped "crusts" were significantly lower at oiled sites, but as with Ralfsia alone, there were few anywhere. Algal canopy cover was much lower at the oiled sites than the unoiled; this may be because of the high cover of mussels and barnacles at these sites, outcompeting algae.

In the Mid quadrats there were 6 species and 3 groupings showing significant treatment effects (Table 8). Polysiphonia spp. had greater abundance at "oiled" areas, which presumably is a spurious result. It does well on barnacles and mussels, both of which were abundant at the "oiled" areas. The limpet Lottia pelta was less abundant in the oiled areas, but was very patchy overall (absent in some non-oiled, non-north areas as well) -- at this level, where no oil was ever seen, it is very unlikely that this was a true oil effect. The limpets L. digitalis and L. strigatella were more abundant overall at the "oiled" sites. However, there were none at Second Beach, so this effect was driven entirely by the very high numbers at Ocean Shores. The abundances of these limpets correlate with that of the gooseneck barnacle Pollicipes; both sets of species were most abundant at Ocean Shores ("oiled") and Starfish Point (unoiled). The mussel Mytilus edulis was rare at the oiled sites in 1989, leading to a significant treatment effect. There was subsequently a large mussel set at Ocean Shores, so that by summer 1990 there was over 40% mean mussel cover at this level; this may be random variation in this "weedy" species, or a post-freeze or post-oil effect. The California mussel was present in any numbers only at two of the unoiled sites, leading to a significant treatment effect; however, as described above, the abundance of this mussel in quadrats is very much dependent on the exact tidal height at that site, and this varied. Recently settled barnacles were present only at the two oiled sites, perhaps just due to overall patchiness.

The three groupings that showed treatment effects all had higher abundance at the oiled sites. Little foliose red algal or overall canopy cover existed at the sand-impacted sites, leading to the slightly higher means at the oiled areas. Barnacles were abundant at the two oiled sites but also at the two sandy sites, perhaps because of reduced algal competition in these areas.

In the Low quadrats, only 6 species and 2 groupings showed significant treatment effects (Table 9). Two species, the red algae Microcladia and erect corallines, were less abundant at the oiled sites, but patchy among all sites. Encrusting corallines were also less abundant in the oiled, but only because Ocean Shores had none (Second Beach had a high percent); this is unlikely to be an oil effect. Two other species, the red alga Iridaea splendens and the barnacle Balanus glandula were more abundant at the oiled sites, probably again simply due to patchiness. The smaller barnacle Chthamalus, and acorn barnacles in general, were very abundant at Ocean Shores, perhaps as an indication of how disturbed this area is. The seastar Leptasterias, and the general grouping of seastars, were abundant at the two sand-impacted sites but absent at the oiled sites; however, they were also absent at the other 3 unoiled sites. This suggests that they "like" the sand, or are attracted to the abundant barnacles at these sites, or are hiding in the holes that were abundant in the low intertidal at the sandy sites.

Overall, then, there are no differences in organismal abundance that can be attributed unambiguously to the impacts of oil. Most of the significant "treatment" effects could be attributed to the freeze, or to other factors such as the compass bearing or the degree of sand impact on the sites. While we cannot say for certain that there were no oil impacts, the complete absence of remnants of oil at the rocky sites combined with the above site-to-site differences make other explanations more parsimonious.

4.2.10 Rocky Shore Structuring Processes: Discussion

The organismal diversity of the rocky shores of this region is strikingly high for a narrow strip of rock in an environment that is usually considered physically stressful. Many factors probably contribute to this diversity: 1) the Pacific Ocean is an old ocean whose rocky shores (unlike those in New England, for instance) have been an undisturbed haven for plants and animals for tens of thousands of years; 2) the relatively low degree of seasonality of water and air temperatures puts less stress on both plants and animals than is experienced in many other temperate rocky coasts; 3) the strong upwelling off the coast of the Pacific Northwest brings nutrient-rich, cold waters to the nearshore zone, allowing extremely high plant productivity. This provides food and habitat for invertebrates that suspension feed from the rich waters or graze on algae, or in turn prey on these primary consumers; 4) there is a broad range of habitats available (rock of different exposures, pools, crevices, underhangs, "biotic habitats"), providing "niches" for many sorts of organisms; and 5) historically very little development, pollution, harvesting, or other human intervention has disturbed these areas.

Habitat heterogeneity clearly contributes to species diversity. Although in most zones there are dominant plants and animals that by definition "consume" a substantial portion of local resources (space or light), they also provide habitat for other organisms that live in the shade and damp of their canopy or the interstices between their shells. Mussel beds are known to harbor over 200 species of small organisms which find shelter on, among, or under the complex mass of mussels (Suchanek 1986). Algae that grow as dense mats, such as *Iridaea* spp., *Endocladia*, *Neorhodomela*, and others similarly provide microhabitats for animals that use them as refuges from predation, wave action, or physiologically stressful conditions at low tide. In addition, many of the 97 algal species in these habitats appear to require the cover of larger algae over them, and could be called "obligate understory" species (Dayton 1975). Thus the presence and health of the dominant species is likely to be critical to the survival of many of the other organisms in these communities.

The processes affecting broad patterns of distribution and abundance are relatively well understood in exposed-coast rocky shore habitats. **Disturbance** by waves and logs is clearly important both in some of the patterns of seasonal abundance and in stochastic patch-creation at all levels. A number of the seasonal patterns (Figs. 2-18) such as wintertime losses or migrations of limpets and littorinids, and losses of algae such as *Dilsea* and *Fucus* are likely a direct result of the increased wave activity in the fall and winter. Of broader importance is the patch (=bare space) forming activities of waves and logs. In mussel beds, it has long been known (Paine and Levin 1981) that winter storms create large patches that then gradual successional changes and gradually are recolonized by mussels. This dynamic process of patch "birth and death" increases the diversity of the mussel zone by keeping this one highly competitive species from dominating all the space all the time. Very large open patches were created in the Chilean Point mussel beds in an unusually late storm early in June 1988, and much of this open space was still visible 2 years later.

Wave disturbance is probably also responsible in part for the lack of a single algal dominant in low and mid zones at most of the sites. These zones were often a mosaic of patches of different algal species, presumably caused either by successional events out of phase with each other or by small differences in wave exposure between microhabitats (as described for Second Beach, above). Another source of disturbance is that patches of the soft and unstable sandstone or conglomerate which are the dominant rock types on this coast occasionally (seasonally?) slough off, thus removing any organisms attached there. One whole 'permanent' quadrat at Chilean Point Exposed was lost this way during the course of the study, and smaller patches of completely bare, newly-exposed rock were seen occasionally at other sites. The dynamic system of disturbance, succession, and recovery created by these patch-forming processes contribute not only to the diversity of the rocky shores, but to the difficulty of interpreting any change seen as being natural vs. freeze-induced vs. oil-induced.

Sand disturbance is a process of critical importance at a number of the study sites, and explains many of the differences among rocky sites. Overriding processes controlling diversity, distribution, and abundance of organisms in these sites are disturbance and recruitment. Sand, wave-borne cobbles, and wave-borne logs all create bare patches on the rock, especially in the winter. Seasonal movements of sand up and down the beach will totally cover and uncover areas of rock projecting from the sand, probably killing many organisms in the process. Diversity at the sand-impacted rocky sites in the Kalaloch region (Starfish Point and Browns Point) was clearly lower both for plants and animals than at the exposed non-sandy sites (Table 10). The Ocean Shores jetty, which also showed signs of sand scour, had extremely low diversity (Table 10).

Figure 20 illustrates the abundances of groupings of organisms (barnacles, carnivores, etc.) by level at the different kinds of sites.

Table 10. Numbers of plant species, animal species and total species at rocky intertidal sites (all levels lumped). SFR= Starfish Point, BPR= Brown's Point, TPE= Taylor Point Exposed, CPE= Chilean Point Exposed, 2BR= Second Beach rock, OSJ= Ocean Shores Jetty, CPP= Chilean Point Protected, CBR= Cannonball Rock, and TPP= Taylor Point Protected.

Site	Plant	Animal	Total
SFR	26	35	61
BPR	29	47	76
TPE	54	63	117
CPE	54	48	102
2BR	39	55	94
OSJ	16	32	48
CPP	37	30	67
CBR	55	43	98
TPP	34	31	65

Animals dominated the sand-impacted sites except for at a few low zone areas. Dominant organisms in the high intertidal were similar to those at non-sandy sites, presumably because sand impact on rocks high above the level of the surrounding sand is minimal (also noted in California by Littler et al. 1983). Healthy beds of mussels and barnacles (acorn and gooseneck) were seen at both Starfish and Browns Points. However, the "weedy" (fast-settling and growing) mussel Mytilus edulis was more abundant there than elsewhere (Figure 20C), suggesting that these sites are more disturbed. In mid and low zones, organisms appear to be adapted to the disturbance regime, and some even thrive in the sand burial (see also Bally et al. 1984, McQuaid and Dower 1990). Elsewhere, these zones were dominated by diverse plant assemblages, but under sand influence they tended to be covered by huge settlements of acorn barnacles (Fig. 20B), gooseneck barnacles, or the cloning anemone Anthopleura elegantissima. Pisaster and Leptasterias, which evidently tolerate sand well, were very abundant in mid and low zones (although seldom appearing in quadrats due to their tendency to concentrate in crevices at low tide), consuming mussels, the abundant barnacles, and tube worms. Several sand-tolerant algae such as Dilsea, Laminaria sinclairii, and Polysiphonia spp. were also abundant very low (Fig. 20A: foliose reds); the mechanisms used by these algae to survive the scouring conditions of winter (e.g., regrowth of blades, encrusting holdfasts, turf-like growth form) need to be examined (Stewart 1983). Other organisms in unusual abundance in sandy sites were several species of the chiton Mopalia (Fig. 20C), which were seen relatively rarely elsewhere (also noted by Littler et al. 1983), and extremely dense, tiny limpets. These organisms may be taking advantage of the relative abundance of bare space (with room to graze); there is evidence that juvenile limpets do not settle or survive well under dense algal canopies (Dethier and Duggins 1984). Other chitons, including Katharina and Lepidochitona dentiens (Fig. 20C) seemed to do poorly in the sandy areas (see also D'Antonio 1986) but were common at non-sandy sites. Overall, Ocean Shores shows more similarities in abundances of these species to the two sandy sites than to the other exposed sites (Fig. 20), suggesting that it may be similarly sand impacted.

Sand-impacted areas thus may contain highly specialized communities, maintained by regular physical disturbance. This allows fluctuations between dominance by competitive species, by opportunistic species, and by species whose physiologies and life histories are geared to sand burial (Daly and Mathieson 1977, Littler et al. 1983). In such highly disturbed areas, organisms that reproduce often and recruit well from planktonic larval/spore stages (such as barnacles and M. edulis) will be those dominating the space, except for long-lived species like the California mussel and the cloning anemone that need only recruit occasionally. Most algae do poorly at these sites not only because of the damage to tissues caused by sand scour but because many algal species apparently do not disperse and recruit well (Paine 1979, Sousa 1984, Reed et al. 1988). In addition, if herbivores have less difficulty than algae in withstanding sand, then it will be easier for them to control algal abundance than at sites where algal recruitment and growth is not so restricted. Thus a combination of disturbance and herbivory may reduce algal dominance in sand-impacted areas.

The other unusual organism at the sand-impacted sites was the gregarious sabellid tube worm, Eudistylia vancouveri. Transects run to quantify the abundance of this worm, which in the past has been heavily collected for fishing bait, demonstrated that there is evidence of significant human disturbance to this animal in some areas. Since virtually nothing is known about recruitment or growth rates of this organism, and since humans clearly are capable of having a strong negative impact on it, it is critical that Park personnel continue to enforce the "no collecting" rule at these sites.

Other processes affecting distributions and abundances of organisms include predation, competition, and herbivory. Without experiments, it is impossible to quantify the relative importance of these processes, but some

Figure 20 A. Abundances (Summer 1989 data) of common groups of plants and animals across the intertidal zone, with sites pooled according to physical similarity: sand-impacted rock (SFR and BPR), non-sandy exposed rock (TPE, CPE, 2BR), the anomalous OSJ, and protected rock (CPP, CBR, TPP). V.H. = Very High quadrats, H = High, M = Mid, and L = Low. Functional groupings of species are defined in the text.

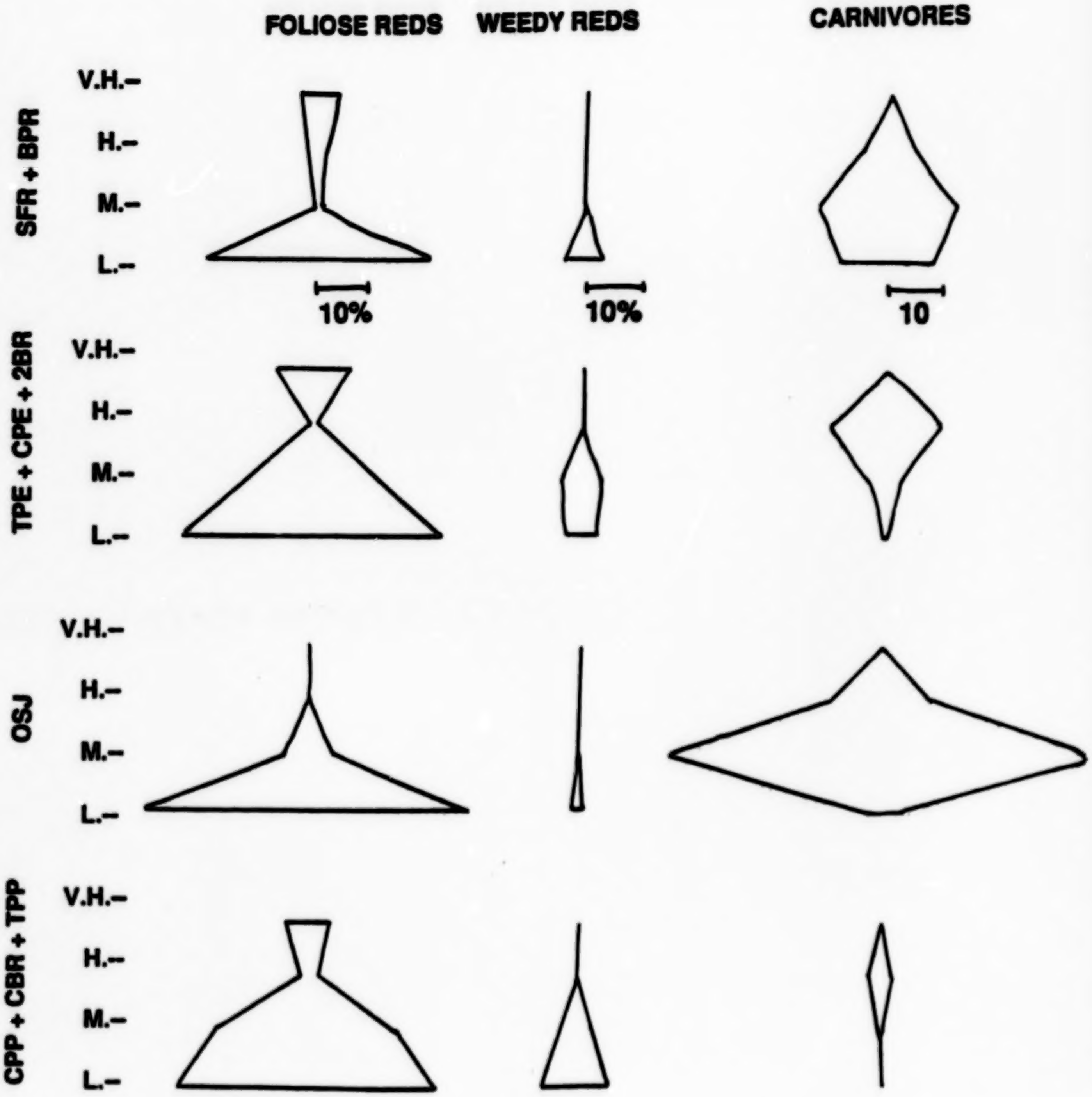


Figure 20 B. Abundances (Summer 1989 data) of common groups of plants and animals across the intertidal zone, with sites pooled according to physical similarity: sand-impacted rock (SFR and BPR), non-sandy exposed rock (TPE, CPE, 2BR), the anomalous OSJ, and protected rock (CPP, CBR, TPP). V.H. = Very High quadrats, H = High, M = Mid, and L = Low. Functional groupings of species are defined in the text.

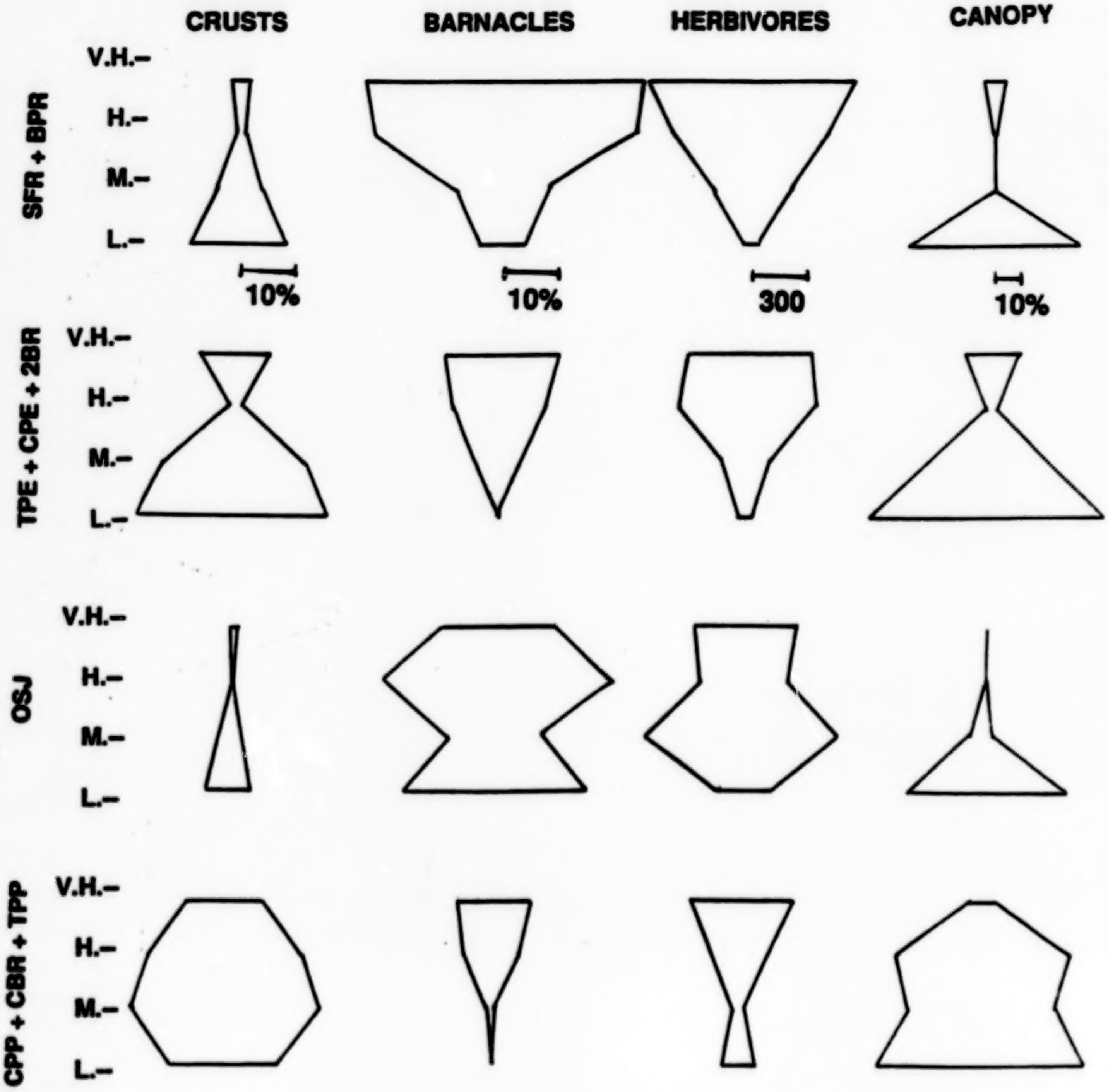
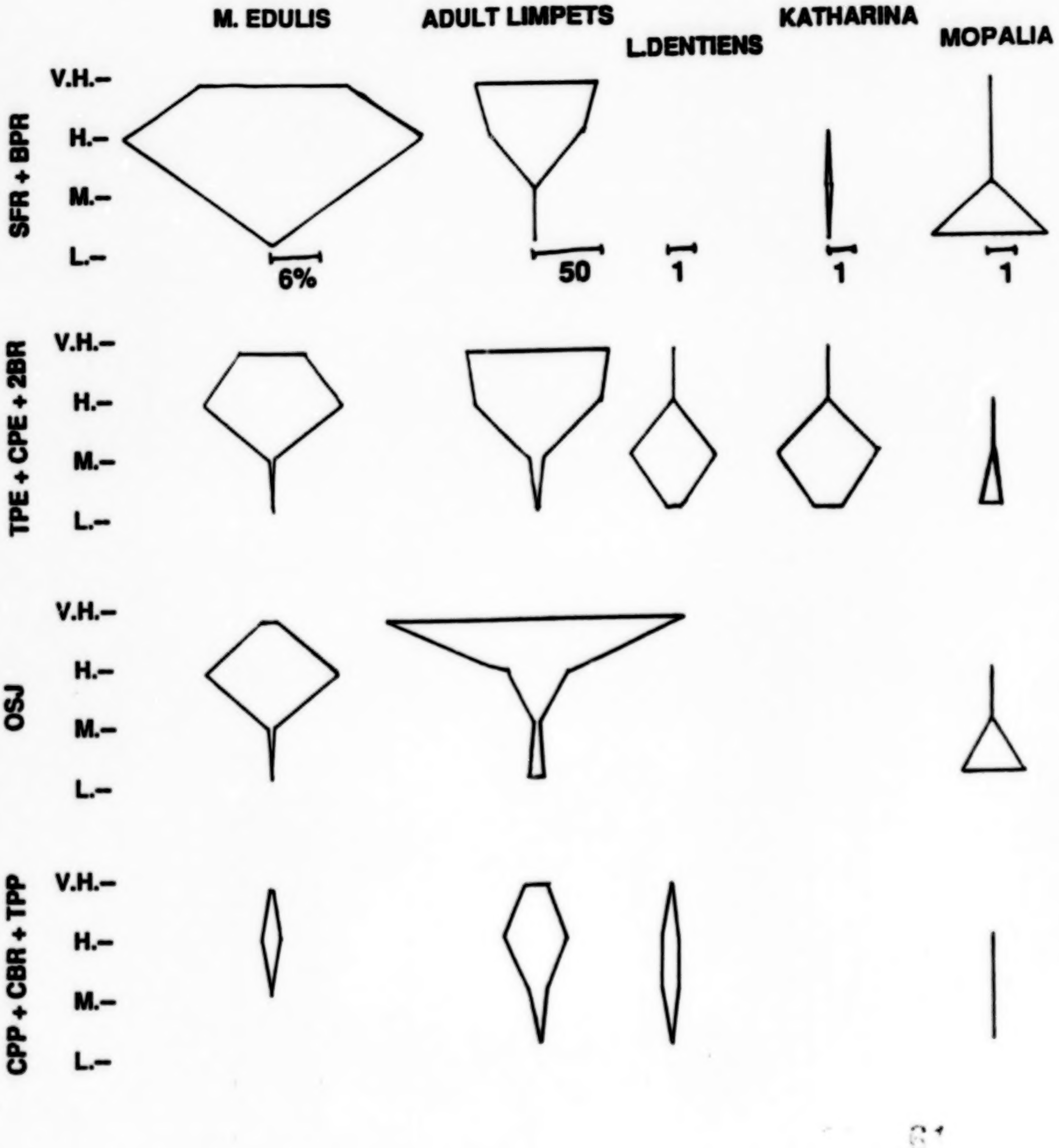


Figure 20 C. Abundances (Summer 1989 data) of common groups of plants and animals across the intertidal zone, with sites pooled according to physical similarity: sand-impacted rock (SFR and BPR), non-sandy exposed rock (TPE, CPE, 2BR), the anomalous OSJ, and protected rock (CPP, CBR, TPP). V.H. = Very High quadrats, H = High, M = Mid, and L = Low. Functional groupings of species are defined in the text.



observations are germane. **Predation** by the seastars Pisaster and Leptasterias and the dogwhelks Nucella spp. on mussels and barnacles was readily visible (see Carnivore abundances in Fig. 20), and greatly reduced the abundance of these organisms in low zones. Elsewhere, seastar predation has been shown experimentally to prevent algae and other organisms from being outcompeted by the dominant mussels (Paine 1966). Less conspicuous predators included nudibranchs consuming sponges and hydroids in low zones, nemertean worms (quite abundant in the mid-high zones) consuming barnacles and polychaetes, various gastropods (e.g. Amphissa) eating a variety of prey in the low intertidal, and fishes (especially sculpins) roaming out of tidepools at high tide to forage on the rock.

Competition is probably important to some extent in all zones. In Very High quadrats, Iridaea cornucopiae has a spreading encrusting base that likely can overgrow other algae and prevent them from resettling. In High and Mid quadrats, Mytilus californianus clearly outcompetes other species, given enough time free from predation and disturbance. In Low quadrats, the larger algae such as Hedophyllum, Alaria, and Laminaria presumably compete amongst themselves for space and light (Dayton 1975), although less is known about these interactions. Smaller algae are likely to be outcompeted by the large ones, either through direct competition for space or light or via whiplash of the substrate by large species. As mentioned above, however, some understory algae apparently require the cover of overstory species.

Herbivory may be relatively unimportant at these sites except in the sand-impacted areas, as described above. Limpets were abundant only in the very high and high zones (Fig. 20C), where they consume microalgae and probably keep mussel beds relatively algal-free. Small chitons (Lepidochitona spp.) were abundant in the low intertidal in some areas (Fig. 20C) but are slow-moving and probably have little impact on algal assemblages. The large leather chiton Katharina, which controls low intertidal algal assemblages in the San Juan Islands (Duggins and Dethier 1985), was rarely abundant at these sites (Fig. 20C), and generally did not maintain "bare" areas as it does in the San Juans. At a few sites Katharina may have contributed to the lack of non-crustose understory algae beneath canopies of kelps. All these herbivorous molluscs may be limited by predation in the Park; gulls eat limpets and chitons, oystercatchers voraciously consume limpets, and both of the abundant seastar species consume limpets and chitons when more preferred prey (such as barnacles and mussels) are not available. Thus the abundance of predators may keep herbivory low, and be indirectly responsible for the lush algal growth and high diversity in the low intertidal zone.

Urchin abundance was extemely patchy across the sites examined, and this pattern is harder to explain. Urchins dominated very low zones at Chilean Point and are abundant at sites to the north of the Park, but were rare or absent at all the other rocky sites sampled. No predators could account for this pattern except for perhaps at Cape Alava, where the resident sea otter population may be able to remove urchins from this zone. Urchins are probably negatively affected by sand, which may explain their absence from the Kalaloch region and from other areas affected by sediment. Their absence from Taylor Point is a mystery; it is possible that they cannot cling to or burrow into the conglomerate rock there, as they do elsewhere into the soft sandstone.

Protected areas differed dramatically from exposed areas in species composition, and probably in structuring processes. Abundances of some species are illustrated in Fig. 20, and mean abundances of all common species are given in Tables 11-14. Physical disturbance from waves is less, but due to the lack of spray, these habitats in some ways are more physically stressful (due to desiccation) than are the wave exposed ones. This may in part account for the generally lower diversity at some of these sites, especially Chilean Point and Taylor Point (Table 10). In addition, sand may

Table 11. Mean and one standard deviation abundances of plants and animals in the **Very High** quadrats at the wave-protected rocky sites, summer 1989 data. Only rare species are excluded. CBR= Cannonball Rock, CPP= Chilean Point Protected, and TPP= Taylor Point Protected.

	CBR	CPP	TPP
Fucus	0.	2.6 (1.1)	4.3 (6.5)
Endocladia	0.	1.0 (0.6)	0.3 (0.3)
Mastocarpus	0.	21.7 (19.7)	1.0 (1.2)
"Petrocelis"	0.	2.2 (2.2)	0.9 (0.2)
Hildenbrandia	0.	0.5 (0.4)	0.1 0.2)
Arthopyrenia	22.6 (31.0)	32.0 (25.9)	0.
Bare	38.4 (39.6)	22.0 (21.4)	76.6 (9.1)
M. edulis	0.	0.	1.2 (1.8)
Balanus	0.	7.0 (4.8)	4.6 (6.3)
Chthamalus	0.	0.9 (0.6)	14.4 (9.9)
Littorina	0.	280. (202)	740. (356)
L. strigatella & *digitalis*	0.	9.2 (4.2)	33.0 (28.6)
Foliose reds	0.	22.7 (19.2)	1.3 (1.3)
Crusts	0.	34.7 (27.1)	1.0 (0.4)
Barnacles	0.	7.9 (5.4)	19.0 8.1
Herbivores	0.	389. (118)	773. (367)
Algal canopy	0.	25.3 (19.8)	5.6 (6.4)

Table 12. Mean and one standard deviation abundances of plants and animals in the **High** quadrats at the wave-protected rocky sites, summer 1989 data. Only rare species are excluded. CBR= Cannonball Rock, CPP= Chilean Point Protected, and TPP= Taylor Point Protected.

	CBR	CPP	TPP
Fucus	45.6 (23.3)	56. (18.5)	44.2 (30.6)
Cladophora	0.2 (0.4)	1.6 (2.5)	10.9 (13.9)
Endocladia	5.8 (2.8)	22.4 (6.4)	8.0 (7.9)
Ralfsia	1.7 (0.6)	12. (6.7)	10.8 (9.1)
Hildenbrandia	51. (23.8)	0.4 (0.4)	0.8 (0.8)
"Petrocelis"	5.6 (3.8)	0.2 (0.3)	0.9 (0.6)
Bare	13.2 (15.5)	42.6 (17.7)	17.0 (23.9)
Juvenile limpets	13. (10)	200. (50)	0.
L. pelta	2.8 (2.6)	1.8 (1.8)	0.6 (1.3)
Littorina	239. (429)	382. (45)	69. (34)
M. edulis	0.	0.	1.5 (2)
Idotea	0.8 (1.8)	21. (4.2)	2.4 (2.8)
Pagurus	3.6 (4.2)	10. (13.7)	10. (13.7)
Balanus	3.8 (4.8)	0.2 (0.4)	5.2 (2.6)
Chthamalus	14.7 (16.1)	0.8 (0.2)	7.2 (3.6)
L. strigatella & digitalis	19. (10)	0.8 (1.1)	113. (60)
Nucella	9.2 (11.9)	2. (1.4)	0.4 (0.9)
Crusts	58.3 (28.2)	12.6 (7.2)	12.5 (9.0)
Barnacles	18.5 (19.7)	1.0 (0.4)	12.4 (4.0)
Mussels	0.	0.	1.5 (2.0)
Herbivores	274. (426)	585. (49)	183. (67)
Carnivores	0.	2.0 (1.4)	0.4 (0.9)
Algal Canopy	51.6 (24.8)	79.0 (19.7)	62.3 (32.1)

Table 13. Mean and one standard deviation abundances of plants and animals in the **Mid** quadrats at the wave-protected rocky sites, summer 1989 data. Only rare species are excluded. CBR= Cannonball Rock, CPP= Chilean Point Protected, and TPP= Taylor Point Protected.

	CBR	CPP	TPP
Fucus	40. (28.5)	13.2 (10.7)	3.8 (4.8)
Mastocarpus	8.8 (2.3)	15. (12.9)	10.4 (4.3)
Endocladia	5.4 (8.4)	24.6 (17.4)	0.1 (0.2)
Analipus	0.1 (0.2)	2.4 (2)	0.
Polysiphonia	0.	3.2 (6.6)	0.8 (0.8)
Cladophora	0.	0.6 (1.3)	7.2 (7.8)
Halosaccion	17. (26.4)	0.1 (0.2)	0.1 (0.2)
Ulva	3. (1.6)	3.9 (6.2)	1.2 (1.3)
Phaeostrophion	0..	2.4 (5.4)	2. (1.8)
Erect Corallines	1.2 (2.7)	0.1 (0.2)	0.
Hildenbrandia	32.6 (21.2)	5.1 (6.3)	0.3 (0.4)
Ralfsia	10.2 (7.1)	27. (5.7)	17.8 (26.9)
"Petrocelis"	2.6 (1.8)	1.3 (1.2)	0.7 (0.4)
Bare	7.8 (9.2)	4.8 (3.9)	2.6 (0.9)
Balanus	0.	0.1 (0.2)	0.9 (1.7)
Chthamalus	10.8 (11.2)	7. (5.6)	0.5 (0.4)
L. pelta	0.2 (0.4)	12.8 (20.8)	0.
Tectura	18.6 (14.5)	0.	0.
Littorina	0.	1. (2.2)	7. (8)
Lacuna	40. (22)	16. (21.6)	220. (255)
Lepidochitona	1.6 (2.2)	0.	0.
Idotea	0.	1.4 (1.9)	0.8 (1.8)
Pagurus	4.2 (5.3)	10. (13.7)	0.
Juvenile limpets	50. (71)	110. (55)	2. (4)
Foliose reds	51.5 (28.5)	35.1 (13.3)	15.7 (4.3)
Weedy algae	17.5 (26.4)	2.5 (2.2)	0.1 (0.2)
Crusts	47.0 (15.5)	35.2 (6.7)	21.1 (27.7)
Barnacles	0.	2.5 (5.3)	2.9 (1.8)
Herbivores	50.2 (70.9)	124. (74)	9.0 (10.2)
Canopy	77.3 (25.1)	64.3 (13.7)	24.3 (10.1)

Table 14. Mean and one standard deviation abundances of plants and animals in the Low quadrats at the wave-protected rocky sites, summer 1989 data. Only rare species are excluded. CBR= Cannonball Rock, CPP= Chilean Point Protected, and TPP= Taylor Point Protected.

	CBR	CPP	TPP
Dilsea	13.2 (17.8)	5. (6)	24.8 (22.8)
Polysiphonia	16.8 (9.2)	14.4 (9.1)	4. (2.4)
Cryptopleura	1.2 (2.7)	0.	0.1 (0.2)
Odonthalia	9.2 (5.4)	6. (4.2)	0.1 (0.2)
Phyllospadix	10.4 (22.2)	0.	0.
Iridaea	12.6 (24)	2.2 (1.5)	5.4 (5.7)
Mastocarpus	2. (3.5)	0.2 (0.3)	5.6 (1.7)
Alaria	9. (8.9)	0.	0.
Laminaria	8.4 (17.7)	0.	0.
Egregia	7. (9.7)	12.4 (17.6)	0.
Neorhodomela	2. (2.8)	2.8 (3.3)	7.3 (15.4)
Ptilota	1.3 (1.7)	2.6 (3.8)	1.3 (2.6)
Phaeostrophion	0.4 (0.9)	25.6 (20.8)	9.3 (8.3)
Halosaccion	3.6 (3.3)	0.2 (0.3)	0.2 (0.3)
Erect Corallines	2.8 (1.3)	0.2 (0.3)	2. (0.7)
Encrusting Corallines	12.2 (13)	0.8 (1.3)	2. (0.7)
Ralfsia	4.4 (3)	0.2 (0.3)	7.6 (8.3)
Hildenbrandia	32.8 (22.6)	0.	0.
Bare	0.	0.	3. (4.5)
Lacuna	320. (246)	32. (25)	135. (204)
Pagurus	26. (23.8)	1. (1.7)	0.
Leptasterias	0.	0.	1.2 (1.1)
Idotea	0.	0.	1.4 (1.7)
Sabellids	0.	0.4 (0.9)	7.6 (6.1)
Alia	22. (25.9)	3. (4.5)	15. (13.7)
Kelp	24.4 (9.7)	12.4 (17.6)	0.
Foliose reds	61.9 (30.2)	33.4 (18.8)	48.8 (22.4)
Weedy algae	20.4 (6.8)	14.6 (9.2)	4.2 (2.4)
Crusts	49.4 (22.2)	1.0 (1.1)	9.6 (8.6)
Barnacles	0.9 (1.0)	0.	0.1 (0.2)
Herbivores	342. (263)	35. (21)	150. (210)
Starfish	0.	0.	1.2 (1.1)
Algal canopy	99.9 (25.3)	71.6 (34.8)	60.1 (19.1)

seasonally foul flat areas of rock or the bottoms of pools, smothering many of the more sensitive organisms.

Predation may be more severe in protected areas since predators need to expend less time and energy clinging to the rocks than they must in highly exposed habitats, and can forage more efficiently (e.g., Menge 1978, Robles 1987, Etter 1989). The numbers of seastars and whelks were low in these sites, however (e.g., Fig. 20A); it is impossible to say whether this is because their food items are scarce (or all eaten) or for other reasons. Barnacles and mussels were consistently scarcer (at all tidal heights) in protected than in exposed areas (Figs. 20B,C); this could be caused by sedimentation or by predation. Herbivorous invertebrates, too, are relatively scarce (Fig. 20B), especially in mid and low zones, and there is less bare space on the rock in these zones (cf. Tables 11-14 with 6-9). As a result of lower herbivory and lower wave-induced disturbance, algal canopy cover was generally higher in protected than in exposed areas (Fig. 20B). This was especially true in High quadrats, which in protected areas were dominated by a heavy canopy of *Fucus*.

4.3 RESULTS: COBBLE AREAS

4.3.1 Habitat Descriptions and Site to Site Variation

General descriptions of cobble habitats are difficult given the variation in substrate size, slope, and horizontal extent of the benches. The major determinants of what organisms are found in a given area seem to be "grain" size, and presence or absence of standing water. Larger cobbles and bedrock are stable and occupied by typical rocky-shore organisms, smaller cobbles are unstable (rolling during winter storms) and occupied by opportunistic plants and animals, and sands and muds contain different infaunas. Some species such as the mud shrimp *Upogebia* and some clams dig readily into coarse, unsorted mud/gravel, whereas other species such as many polychaetes require finer muds. Sediments that receive little wave action tend to be anaerobic just below the surface, limiting some species' distributions. Many sections of these benches consist of large, shallow pools, which either remain full of water through a tidal cycle, or drain only slowly. Even though these pools clearly warm up during daytime low tides, they contain a number of otherwise subtidal organisms (see below). The percentages of rock (stable) vs. cobble + sediment (unstable) and of pool at each of the levels in the transects is given in Table 15.

The transect site at Kayostla Beach (Table 1) was chosen as an "oiled" site by Battelle researchers to contrast with "unoiled" cobble further to the north. Unfortunately, the substrata and slope of this transect were quite different from all the other cobble transects; the transect was relatively short and steep and consisted largely of large boulders and clean sand. The organisms found here were very different from those in other cobble transects; consequently these data are omitted from many analyses discussed below.

As on rocky shores, some zonation of plants and animals could be seen among levels. Due to the long, flat nature of the transect areas, and to the mix of rock, pool, and sediment found at each height, however, this zonation is not distinct. Below are described the general types of plants and animals found at each level in the cobble transects. Level 1 was the highest level, and Level 8 was usually just above low water level on spring tides. Data on species abundances are given in Tables 17-21.

Level 1 varied highly in tidal height and substratum type, and therefore species composition. In some transects this level was composed of fairly dry sand (often a sand or gravel area occurred above the cobble benches); these

Table 15: Percentages of substrate types and permanent pool cover for cobble transects (S89, W90, S90 data averaged, since quadrat sites at these different dates were independent). CAC= Cape Alava Cobble, CPC= Chilean Point Cobble, NMI= Norwegian Memorial I, NMII= Norwegian Memorial II, and SPC= Sand Point Cobble.

		SITES				
Level	Substrate	CAC	CPC	NMI	NMII	SPC
1	Rock	4	3	0	70	0
	Cobble/Sediment	96	97	100	30	100
	Pool	79	2	0	0	0
2	Rock	2	46	48	81	30
	Cobble/Sediment	98	54	52	19	70
	Pool	72	61	14	65	36
3	Rock	18	33	62	46	35
	Cobble/Sediment	82	67	38	54	65
	Pool	8	17	55	42	62
4	Rock	33	40	25	31	64
	Cobble/Sediment	67	60	75	69	36
	Pool	30	47	82	79	50
5	Rock	0	44	77	24	31
	Cobble/Sediment	100	56	23	76	69
	Pool	80	24	55	80	42
6	Rock	13	71	17	25	39
	Cobble/Sediment	87	29	83	75	61
	Pool	22	63	55	79	18
7	Rock	3	-	35	26	40
	Cobble/Sediment	97	-	65	74	60
	Pool	47	-	84	39	35
8	Rock	25	-	40	63	82
	Cobble/Sediment	75	-	60	37	18
	Pool	50	-	68	51	7

had only amphipod beach hoppers (fam. Talitridae). Some sites had fine sands and muds in a shallow pool area; these were occupied by dense, tiny spionid polychaetes. Other areas had substrata of gravel and small cobbles, occupied by amphipods, periwinkles, and the shore crabs *Hemigrapsus* spp. Diversity was low at all sites at this level (Fig. 21); like any high intertidal area, there are great physical stresses here in terms of desiccation, high and low temperatures, and great salinity variation. In addition, areas with fine sediments were often anaerobic due to the low wave action and to the large amount of organic matter draining down into this zone from rotting drift algae above. Algae in this zone (if any) consisted of crusts and ulvoid algae, especially *Enteromorpha*. One site had abundant arenicolid polychaetes, and another contained abundant syllids.

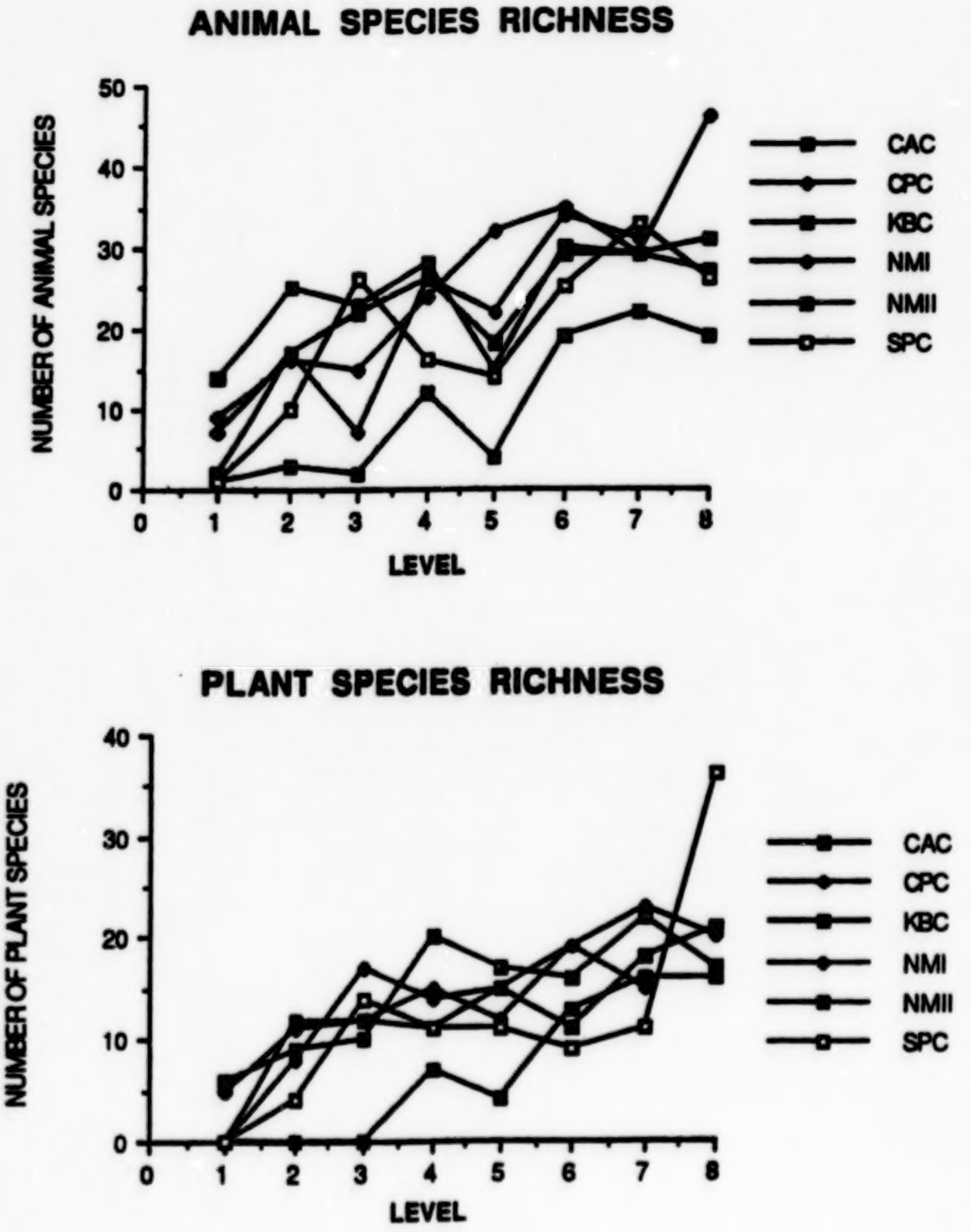
Level 2 contained more rock (boulders and bedrock) than did Level 1 at most sites. Some sites had large shallow pools. Dominant algae were ulvoids and crusts, as on rocks at Level 1. Dominant animals were more diverse than at Level 1, and included small hermit crabs (*Pagurus* spp.), barnacles (*Balanus glandula* and *Chthamalus*), *Littorina*, the herbivorous snail *Tegula funebralis*, and some limpets (*Lottia strigatella*, *L. digitalis*, and *Tectura fenestrata*). Level 2 at Sand Point was effectively higher than at the other sites, and was dominated by spionids and amphipods. Sediments at most sites contained the orbiniid polychaetes *Naineris* spp., some spionids, capitellids, and flabelliferid isopods. At Cape Alava there was evidence of some clams (*Macoma* spp. and *Transennella tantilla*). Most of these organisms are either suspension feeders or detritivores, consuming the microalgae on the rocks and the drift algae in the water at this level.

Level 3 at all sites contained a mixture of rock and sediments, mostly muddy sand, with some pool area (with the exception of the Kayostla site, which was mostly clean sand). In many transects this was the beginning of the *Fucus* zone, the dominant alga on many rocks. Other prominent algae were crusts, *Gelidium coulteri*, and *Mastocarpus papillatus*. While the latter species is common on rocky shores of this coastline, the former was rarely seen except in cobble transects (see below). Common animals included hermit crabs, *Tegula*, *Littorina*, some barnacles, the limpets *Tectura scutum* and *Lottia* spp., plus *T. fenestrata* at some sites. Sediments contained the bivalves *Transennella*, *Macoma* spp., *Mya arenaria*, and *Protothaca staminea*; the crustaceans *Hemigrapsus* spp., porcelain crabs *Petrolisthes* spp., mud shrimp *Upogebia*, and other shrimp; sipunculid worms; and many polychaetes, including spionids, lumbrinerids, terebellids, and maldanids.

Level 4 generally had more pool area and more sediment (the two generally went together) than Level 3. Dominant algae included *Fucus* and *Mastocarpus* (out of pools), encrusting corallines (in pools), and other crusts and *Gelidium* in both places. Animals included the species listed for level 3, plus many small gastropods that tended to be found at all lower levels: *Lirularia* spp., *Alia* spp., *Margarites pupillus*, and *Lacuna* spp. Sediments tended to be riddled with holes occupied by bivalves (species above) plus mud shrimp. Small, abundant ophiuroids were first seen in the sediments at this level, as were the burrowing cucumbers *Leptosynapta clarki*. Polychaetes included lumbrinerids, maldanids, orbiniids, and capitellids. Other organisms included sipunculids, flabelliferid isopods, *Petrolisthes* spp., and most unusually, an unidentified (?undescribed) species of enteropneust, which are very uncommon in Washington state. Pools also contained shrimp and many small fishes, including cottids, gobies, and blennies. The Kayostla site remained dominated by sand.

Level 5 generally had a similar mix of substrate types as Level 4, and very similar organisms; often there was little visible difference in tidal height between the two levels. The main difference was that while *Mastocarpus*, *Fucus*, crusts, and *Gelidium* were still important at this level, pools here and lower were often dominated by the surfgrasses *Phyllospadix* spp.

Figure 21. Species richness (number of species) of animals and of plants across the intertidal zone at cobble areas (Summer 1989 data). Site code names are: CAC= Cape Alava cobble, CPC= Chilean Point cobble, KBC= Kayostla Beach cobble, NMI= Norwegian Memorial transect I, NMII= Norwegian Memorial II, SPC= Sand Point cobble. Level 1 = highest, Level 8 = lowest.



The red alga Neorhodomela larix was also common. Animals included the species listed for Levels 3 and 4 (including the small gastropods, shrimp, and fishes). Sediments contained similar mixes of crabs, worms, isopods, ophiuroids, and clams.

Level 6 was again similar to the previous levels. Some "high" species such as Littorina began to drop out, and a few "lower" common species were added; these included erect coralline algae, the gastropods Searlesia dira and Bittium eschrichtii, more terebellid worms, and sabellariid worms at one site. The Kayostola site still was dominated by Fucus at this level, but also contained algae otherwise found only at sand-impacted rocky areas, including Sphacelaria spp. and Phaeostrophion.

At most sites, Level 7 became abruptly different, often with a visible drop in tidal height. Sites differed in their combinations of rock, sediment, and pools. Level 7 at Chilean Point was the lowest level sampled at that site, and had an unusual substratum of cobbles and rocks that were almost cemented into a sand-clay base. Dominant plants at Level 7 at most sites were Phyllospadix spp., ulvoids, encrusting and erect corallines, and at some sites "lower" species such as the red Iridaea splendens and the kelp Egregia menziesii. "Higher" species such as Fucus, Mastocarpus, Gelidium, and Neorhodomela were still found in some quadrats. Dominant animals included hermit crabs, porcelain crabs (but not Hemigrapsus), Tegula and other small gastropods (but not Littorina), and several chiton species. The sediment contained many of the same polychaete families, plus occasional orbiniids, onuphids, and oweniids, and small Cancer crabs buried under cobbles. Sipunculids were fairly common.

Level 8 was generally right at the lowest tide level, and at most sites contained a dramatically different set of plants and animals. Beds of Macrocystis integrifolia were often close offshore, and some transects actually contained some of this kelp in the lowest quadrats. Dominant algae were Gastroclonium, Odonthalia floccosa, Iridaea splendens, Prionitis spp., Dilsea californica, Phyllospadix spp., and encrusting and erect corallines. Common animals included the ubiquitous hermit crabs, Tegula, and small gastropods, but also included the chiton Tonicella lineata, sponges, nudibranchs, colonial and solitary tunicates, majid, porcelanid, and cancrid crabs, the seastars Leptasterias and Henricia, and a wide variety of other species. Sediments contained ophiuroids, nereids, lumbrinerids, terebellids, orbiniids, sabellariids, spionids, and sipunculids. Level 8 at the Kayostola site was characterized by clean sand and boulders, with Phyllospadix, Neorhodomela, Dilsea, and Odonthalia.

Figure 22 graphs the abundance of some of the common taxa and of functional groups of species such as total algal canopy cover and total barnacle cover. Site to site variation is evident but patterns are difficult to discern except for general additions and losses of species with changing tidal height. Some significant differences from rocky shores (Fig. 20) are that 1) barnacles are relatively uncommon; 2) crustose algae are very common, 3) Fucus is abundant but highly variable in cover; and 4) a number of species (besides the sediment dwelling species) never seen on rocky shores are common here (see below).

4.3.2 Unusual Aspects of the Cobble Areas

We recorded 105 plant and 229 animal species in the cobble transects (Appendix C). Most sites had nearly twice as many animal as plant species (Table 16). This high proportion of animal species was unusual; all the rocky sites had nearly equal proportions of plants and animals (Table 10). This difference probably exists because cobble is a relatively poor habitat for plants, most of which need non-sedimented, stable substrata, but a good one

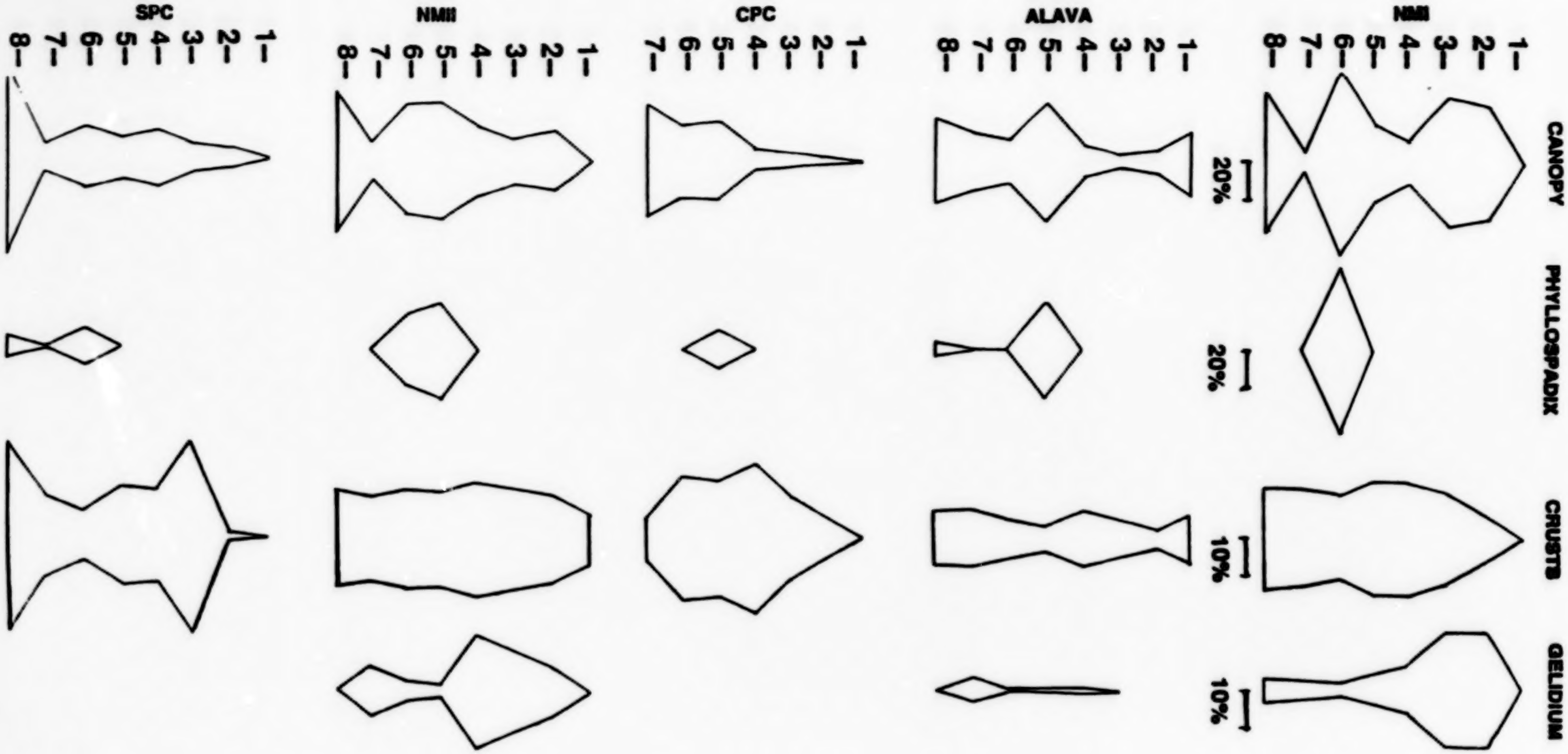


Figure 22 A. Abundances (Summer 1989 data) of common taxa and groupings of functionally similar organisms across the intertidal zone in the cobble transects. Site code names are: Alava= Cape Alava cobble, CPC= Chilean Point cobble, NMI= Norwegian Memorial transect I, NMII= Norwegian Memorial II, SPC= Sand Point cobble. Level 1 = highest, Level 8 = lowest. Groupings are defined in the text.

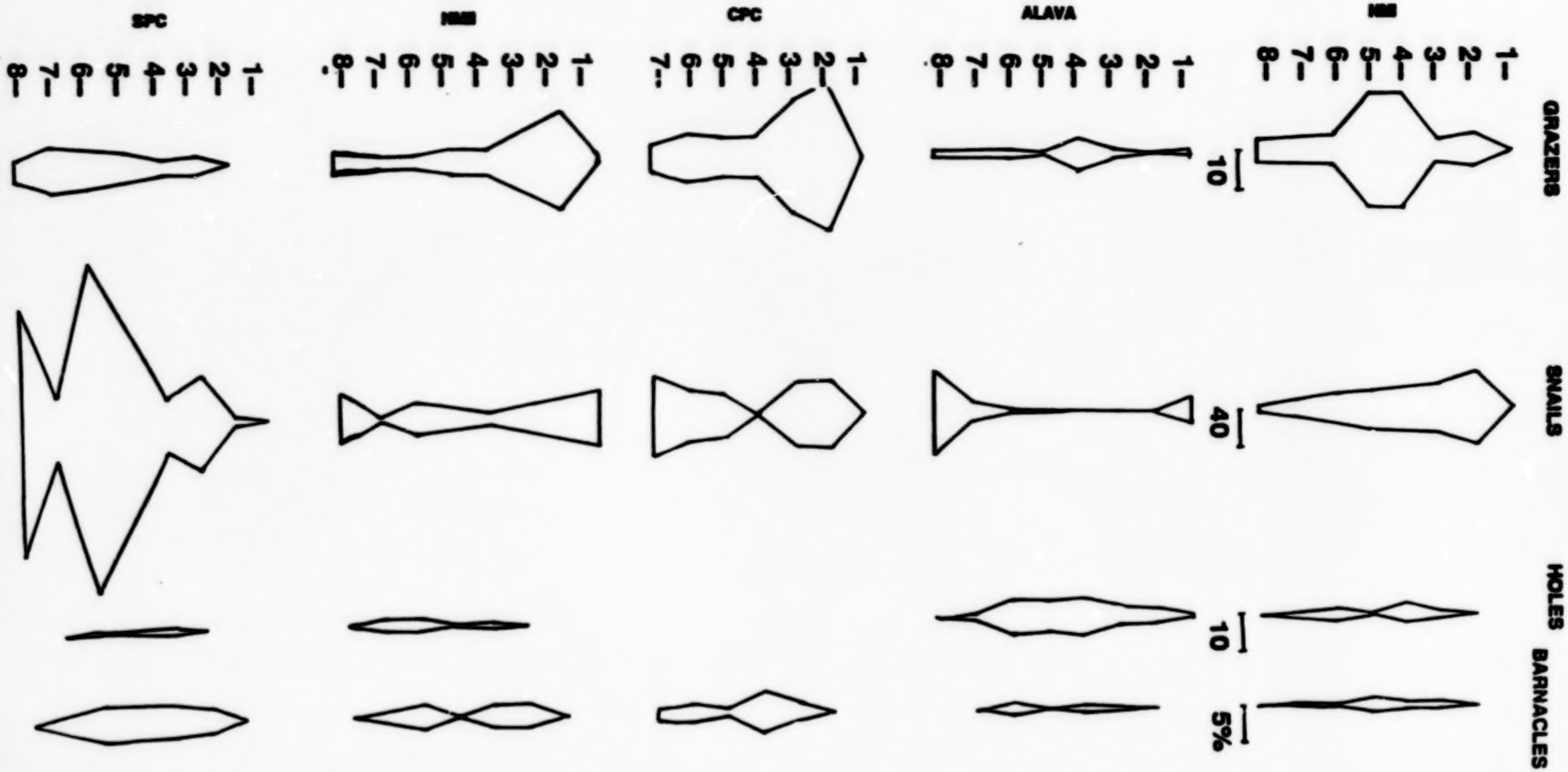


Figure 22 B. Abundances (Summer 1989 data) of common taxa and groupings of functionally similar organisms across the intertidal zone in the cobble transects. Site code names are: Alava= Cape Alava cobble, CPC= Chilean Point cobble, NMI= Norwegian Memorial transect I, NMII= Norwegian Memorial II, SPC= Sand Point cobble. Level 1 = highest, Level 8 = lowest. Groupings are defined in the text.

Table 16. Numbers of plant species, animal species and total species at cobble sites (all levels lumped).

Site	Plant	Animal	Total
Sand Point	55	96	151
Norwegian Memorial	67	113	180
Cape Alava	49	98	147
Kayostla Beach	35	52	87
Chilean Point	33	66	99

for animals that live under rocks or actually in the sediment, such as the many species of polychaetes, clams, brittle stars, and small crustaceans. The under-rock habitat contained other organisms seen rarely elsewhere. These included porcelain crabs, grapsid crabs, *Cancer productus*, spirorbid and other polychaetes, the snail *Tegula*, and a wide variety of small gastropods. On one occasion we found an *Octopus*. Juvenile forms of a number of invertebrates appear to use this habitat as a nursery -- the most obvious of these were small cancrid crabs. Other invertebrate species were more common on the cobbles than on bedrock at the rocky sites; these included the chiton *Mopalia muscosa* and the limpet *Tectura fenestrata*. Numerous animals normally found only subtidally such as hydroids, nudibranchs, various gastropods, and the ascidean *Clavelina* were seen only in the large, shallow pools that characterized many of the transects.

The most suitable habitats for plants were the cobbles and boulders in the low intertidal zone, although some algae could be found even at the highest levels. Plant diversity was moderately high in the lowest stations (Fig. 21), where there was often less loose sediment (Table 15), and in the large shallow pools that remained relatively cool even on warm days. Dominant plants included some species that were uncommon elsewhere, such as *Neorhodomela larix* (high), *Cystoseira geminata* (mid and low), three species of *Phyllospadix: P. scouleri, P. serrulatus* and *P. torreyi* (all in pools), and the reds *Odonthalia floccosa, Ceramium* spp., *Gastroclonium* and *Grateloupia* (mostly low). Some transects were heavily dominated by a red alga only seen at one rocky site: *Gelidium coulteri*. This is a warmer-water species that is common in California; it may have thrived in the shallow pools that warmed up significantly during summer days. One low area at Cape Alava was dominated by a remarkable forest of the green alga *Codium fragile*, which was seen only rarely elsewhere in the Park. Several unusual articulated coralline algae were also abundant, e.g. *Lithothrix* and *Serraticardia*.

4.3.3 Freeze Impacts and Seasonal Changes

Since permanent quadrats could not be established in the cobble transects, detailed observations of seasonal changes or impacts of the freeze could not be made. Due to logistic constraints, winter samplings were relatively cursory, consisting largely of quantifying dominant epifauna and flora. These data do not suggest any significant seasonal changes in biota, although subtle changes would not be noticeable; dominant organisms (plant and animal) generally were the same at each level between summer and winter samplings. As in rocky areas, *Fucus* cover was noticeably reduced in the winter, although it remained a dominant organism at the higher levels. Likewise, no obvious freeze impacts were seen at these sites.

4.3.4 Impacts of the Oil Spill

Quantification of oil impacts in the cobble areas is plagued by the absence of before-and-after data, as well as by the other problems that are discussed above for the rocky sites. Tables 17-21 list the abundances of common species at all sites, and show significant site and treatment effects (excluding the anomalous Kayostla site). Functional groupings of organisms for analysis were as follows: Algal Canopy = summed coverage of all erect algae and surfgrass; Crusts = summed primary coverage of all encrusting algae, excluding lichens; Small Snails = *Littorina* spp., *Tegula*, *Lacuna*, *Alia*, *Lirularia*, and *Bittium*; Grazers = all limpets and chitons; Barnacles = all acorn barnacles. "Holes" were simple counts of macroscopic holes in the sediment surface; these were created both by mud shrimp and by clams.

The only site that showed unambiguous oil impact was at the top of site I at Norwegian Memorial (the most heavily oiled site). Here there was an oil

Table 17. Abundances of common species (summer 1989) at **Levels 1 and 2** (pooled at cobble sites). Significant differences are given for a Site Effect (S) and Treatment Effect (T), from ANOVAs, excluding site KBC (see text). Functional groupings are defined in text. NMII= Norwegian Memorial II, SPC= Sand Point Cobble, NMI= Norwegian Memorial I, CAC= Cape Alava Cobble, CPC= Chilean Point Cobble, and KBC= Kayostla Beach Cobble.

	Oiled		Unoiled				Statistics	
	NMII	SPC	NMI	CAC	CPC	KBC	S	T
Fucus	10.3 (24.3)	0.	14.5 (21.8)	8.7 (15.8)	0.	0.		
Ulva	0.	6.0 (9.8)	0.	10.2 (10.4)	0.	0.		
Neorhodomela	0.	0.	0.	1.3 (2.4)	2.3 (4.1)	0.		
Gelidium	6.7 (10.8)	0.	15.0 (18.4)	0.	0.	0.	•	
Hildenbrandia	6.8 (13.9)	0.8 (2.0)	4.5 (6.4)	7.3 (8.9)	0.1 (0.2)	0.		
Ralfsia	11.2 (12.9)	0.	1.7 (3.1)	1.7 (4.1)	6.3 (7.5)	0.		
Pagurus	11.7 (19.7)	0.2 (0.4)	3.8 (4.9)	3.5 (5.8)	1.7 (4.1)	0.		
Littorina	51.7 (55.3)	2.5 (5.2)	35.0 (38.7)	15.3 (23.8)	14.5 (18.4)	0.		
Lepidochitona	0.3 (0.8)	0.	0.	0.2 (0.4)	1.5 (2.1)	0.		
Hemigrapsus	0.8 (2.0)	0.3 (0.8)	1.3 (3.3)	0.7 (0.8)	0.5 (0.8)	0.		
Tegula	2.0 (3.2)	0.	5.3 (7.3)	0.	6.2 (6.8)	0.		
L. pelta	0.5 (0.8)	0.	0.2 (0.4)	0.	0.7 (1.6)	0.		
Holes	0.	0.	0.3 (0.8)	2.7 (2.9)	0.	0.	•	
T. persona	0.5 (0.8)	0.	2.5 (6.1)	0.	0.	0.		
L. strigatella	12.2 (23.9)	0.	1.7 (2.9)	0.8 (1.0)	12.0 (16.0)	0.		
Gnorimo.	0.	8.3 (20.4)	0.	0.	0.8 (2.0)	0.		
Spionids	0.	0.	0.3 (0.8)	4.2 (10.2)	100. (197)	0.		
Algal canopy	17.0 (30.1)	6.0 (9.8)	29.5 (39.8)	20.2 (17.7)	2.3 (4.1)	0.		
Crusts	18.0 (13.6)	0.8 (2.0)	6.2 (7.1)	9.0 (9.3)	6.4 (7.6)	0.		
Small snails	53.7 (45.5)	2.5 (5.2)	40.3 (44.2)	15.3 (23.8)	20.7 (23.4)	0.		
Grazers	13.5 (24.8)	0.	4.3 (6.0)	1.0 (1.0)	20.3 (24.7)	0.		

Table 18. Abundances of common species (summer 1989) at **Levels 3 and 4** (pooled at cobble sites). Significant differences are given for a Site Effect (S) and Treatment Effect (T), from ANOVAs, excluding site KBC (see text). NMII= Norwegian Memorial II, SPC= Sand Point Cobble, NMI= Norwegian Memorial I, CAC= Cape Alava Cobble, CPC= Chilean Point Cobble, and KBC= Kayostia Beach Cobble.

	Oiled		Unoiled				Statistics	
	NMII	SPC	NMI	CAC	CPC	KBC	S	T
Fucus	0.2 (0.4)	19.5 (28.1)	14.2 (34.7)	7.2 (8.6)	0.	0.		
Mastocarpus	9.33 (10.7)	3.2 (18)	10.0 (6.8)	0.3 (0.4)	6.7 (7.4)	0.1 (0.4)	•	
Neorhodomela	0.	0.1 (0.2)	0.	2.2 (3.9)	1.4 (3.2)	0.1 (0.4)		
Gelidium	28.2 (26.1)	0.	21.2 (20.5)	0.7 (1.0)	0.	6.4 (17.6)	•	
Encrusting Corallines	3.7 (1.6)	0.8 (0.8)	2.3 (3.0)	0.3 (0.5)	5.9 (8.2)	0.		
Hildenbrandia	16.2 (13.6)	25.3 (15.8)	18.0 (5.8)	9.8 (10.4)	17.5 (8.8)	0.1 (0.2)		
Ralfsia	8.2 (4.3)	9.5 (11.2)	6.3 (3.7)	2.2 (1.6)	8.5 (9.4)	0.1 (0.4)		
Lichen	0.	6.0 (4.2)	1.0 (2.4)	0.	0.	0.	•	•
Diatoms	0.	0.	0.	43.7 (31.3)	0.	0.	•	•
Pagurus	32.5 (19.9)	32.8 (18.4)	26.7 (20.0)	19.2 (24.0)	6.7 (5.2)	6.4 (17.6)		
Tegula	16.7 (8.3)	7.8 (5.1)	27.5 (11.3)	1.8 (2.0)	3.2 (3.1)	0.2 (0.7)	•	
Transennella	0.	0.	0.	103. (195)	0.	0.	•	•
L. strigatella	4.2 (4.2)	2.7 (2.4)	13.3 (18.2)	0.5 (1.2)	1.3 (2.2)	6.2 (17.7)	•	
Ophiuroids	0.5 (0.5)	0.	1.7 (4.1)	16.7 (25.8)	0.	0.		
Gnorimo.	0.2 (0.4)	0.	0.2 (0.4)	0.	50.7 (76.9)	0.	•	
Maldanids	0.	0.8 (2.0)	0.	18.3 (24.8)	0.	0.		
T. scutum	7.0 (7.7)	0.3 (0.8)	4.2 (6.1)	4.7 (8.3)	16.0 (12.3)	0.		
Balanus	0.2 (0.3)	3.2 (2.6)	0.3 (0.3)	0.1 (0.2)	1.8 (2.2)	0.	•	
Chthamalus	2.8 (1.6)	0.5 (0.3)	0.5 (0.4)	0.5 (0.8)	2.4 (3.8)	0.1 (0.4)		
Littorina	1.0 (2.24)	70.8 (40.1)	24.2 (22.4)	0.2 (0.4)	14.5 (18.6)	63.1 (176)	•	
Lepidochitona	0.	1.7 (2.3)	0.3 (0.8)	0.	2.8 (2.8)	0.	•	
Hemigrapsus	0.3 (0.5)	1.7 (1.6)	2.2 (2.4)	0.	0.7 (1.2)	0.4 (1.1)		
Holes	0.3 (0.8)	0.3 (0.8)	3.2 (2.7)	7.8 (4.9)	0.	0.	•	•

Table 18, cont'd.

	Oiled		Unoiled				Statistics	
	NMII	SPC	NMI	CAC	CPC	KBC	S	I
Algal canopy	37.7 (37.2)	22.8 (27.9)	45.3 (51.0)	10.4 (9.2)	8.1 (7.9)	0.2 (0.7)		
Crusts	28.0 (13.4)	36.6 (17.7)	26.7 (6.9)	12.3 (11.5)	31.9 (12.3)	0.2 (0.5)		
Small snails	17.7 (10.5)	78.7 (38.3)	51.7 (25.0)	2.0 (2.3)	17.7 (21.7)	63.4 (177.2)	*	*
Grazers	11.2 (10.3)	4.7 (4.3)	17.8 (23.4)	5.2 (9.5)	20.2 (13.6)	6.2 (17.7)		
Barnacles	3.0 (1.6)	3.8 (2.9)	0.8 (0.7)	0.6 (0.9)	4.2 (5.9)	0.1 (0.4)		

Table 19. Abundances of common species (summer 1989) at **Levels 5 and 6** (pooled at cobble sites). Significant differences are given for a Site Effect (S) and Treatment Effect (T), from ANOVAs, excluding site KBC (see text). NMII= Norwegian Memorial II, SPC= Sand Point Cobble, NMI= Norwegian Memorial I, CAC= Cape Alava Cobble, CPC= Chilean Point Cobble, and KBC= Kayostla Beach Cobble.

	Oiled		Unoiled				Statistics	
	NMII	SPC	NMI	CAC	CPC	KBC	S	T
Phyllospadix	45.8 (43.3)	9.0 (22.0)	44.2 (50.0)	26.7 (43.2)	5.1 (12.2)	0.		
Fucus	0.	5.5 (9.6)	9.2 (14.3)	7.3 (8.8)	0.1 (0.2)	10.5 (14.3)		
Mastocarpus	0.	12.5 (6.7)	8.3 (13.8)	0.5 (1.2)	34.3 (21.6)	2.0 (1.7)	*	
Neorhodomela	0.3 (0.8)	0.	0.	3.7 (4.5)	0.	2.3 (3.1)	*	
Gelidium	4.8 (4.0)	0.	6.5 (6.1)	0.5 (0.8)	0.	0.	*	
Ceramium	10.9 (12.6)	0.	0.	3.5 (8.1)	0.	0.	*	
Erect Corallines	2.4 (5.7)	0.1 (0.2)	1.4 (2.4)	0.7 (0.8)	0.2 (0.3)	0.4 (0.8)		
Encrusting Corallines	9.8 (7.0)	0.	6.9 (7.6)	0.5 (0.8)	7.9 (9.1)	1.7 (1.9)	*	
"Petrocelis"	0.	4.2 (3.8)	1.2 (1.6)	0.	0.2 (0.4)	0.	*	
Hildenbrandia	7.3 (3.5)	8.2 (6.1)	15.7 (12.7)	7.2 (3.6)	13.3 (8.4)	2.8 (4.0)		
Ralfsia	8.3 (6.7)	6.4 (9.9)	3.3 (4.1)	0.6 (0.8)	13.8 (5.5)	5.1 (5.5)	*	
Lichen	0.	6.2 (7.1)	0.7 (1.6)	0.	0.	0.	*	*
Balanus	0.	2.9 (1.6)	0.2 (0.4)	0.5 (0.8)	0.3 (0.4)	0.	*	
Chthamalus	1.7 (4.1)	1.8 (2.6)	1.0 (1.5)	0.8 (1.6)	1.4 (1.7)	1.4 (1.4)		
T. scutum	4.8 (4.1)	5.3 (5.6)	4.2 (4.7)	1.0 (2.4)	7.7 (9.0)	0.2 (0.4)		
Hemigrapsus	0.	7.5 (10.1)	3.3 (8.2)	4.2 (8.0)	0.	0.		
Tegula	5.2 (4.8)	16.2 (13.8)	14.8 (13.9)	2.3 (3.7)	1.0 (1.1)	1.5 (2.3)	*	
Pagurus	35.0 (23.4)	40.8 (34.7)	18.3 (24.8)	50. (0)	5.8 (4.9)	10.8 (19.6)		
Lepidochitona	0.3 (0.8)	1.2 (1.5)	1.7 (2.4)	0.	1.3 (1.5)	0.		
Ophiuroids	0.8 (1.2)	0.	3.3 (8.2)	17.0 (25.6)	0.2 (0.4)	0.		
Lacuna	16.7 (25.8)	0.	4.2 (10.2)	0.	24.2 (24.8)	0.	*	
L. pelta	0.3 (0.8)	1.0 (2.4)	0.8 (1.6)	0.2 (0.4)	2.7 (6.1)	0.		
L. strigatella	0.	2.3 (2.1)	12.2 (19.0)	0.	0.8 (2.0)	0.	*	
Littorina	0.	230. (152)	17.5 (29.3)	0.	1.8 (2.9)	0.	*	*

Table 19, cont'd.

	Oiled		Unoiled				Statistics	
	NMII	SPC	NMI	CAC	CPC	KBC	S	I
Holes	2.2 (2.3)	0.5 (0.5)	2.0 (2.1)	8.8 (4.0)	0.	0.8 (2.0)	*	
Algal canopy	64.2 (66.4)	27.1 (18.5)	69.6 (36.4)	42.8 (37.5)	39.7 (15.2)	15.2 (17.9)		
Crusts	25.5 (8.0)	18.8 (9.9)	27.0 (13.7)	8.2 (3.7)	35.3 (6.0)	9.6 (9.5)	*	
Small snails	21.8 (25.8)	246. (155)	36.5 (30.8)	2.3 (3.7)	27.0 (24.0)	1.5 (2.3)	*	*
Grazers	5.5 (3.4)	9.8 (4.9)	18.8 (25.8)	1.2 (2.4)	12.5 (12.2)	0.2 (0.4)	*	
Barnacles	1.7 (4.1)	4.7 (1.6)	1.2 (1.9)	1.3 (2.3)	1.8 (1.8)	1.4 (1.4)		

Table 20. Abundances of common species (summer 1989) at Cobble **Level 7**. Significant differences are given for a Site Effect (S) and Treatment Effect (T), from ANOVAs, excluding site KBC (see text). NMII= Norwegian Memorial II, SPC= Sand Point Cobble, NMI= Norwegian Memorial I, CAC= Cape Alava Cobble, CPC= Chilean Point Cobble, and KBC= Kayostla Beach Cobble.

	Oiled		Unoiled				Statistics	
	NMII	SPC	NMI	CAC	CPC	KBC	S	T
Phyllospadix	33.3 (57.7)	33.3 (57.7)	86.7 (23.1)	1.3 (2.3)	0.	95.0 (5.0)		
Egregia	0.	0.	0.	0.	20.0 (19.1)	0.	*	
Ulva	0.	0.	0.	3.0 (1.0)	2.7 (3.1)	6.7 (2.3)		*
Neorhodomela	3.3 (5.8)	0.	0.	5.3 (6.1)	1.3 (1.5)	3.7 (4.0)		
Gastroclonium	2.0 (2.0)	0.	0.	13.7 (10.0)	0.	0.	*	
Mastocarpus	3.0 (2.6)	14.7 (14.2)	4.0 (6.9)	0.	34.0 (19.3)	0.3 (0.6)	*	
Gelidium	13.3 (23.1)	0.	5.0 (8.7)	7.7 (10.8)	0.	0.		
Hildenbrandia	3.3 (2.3)	14.0 (1.7)	2.0 (1.0)	2.0 (3.5)	8.0 (10.4)	0.		
Ralfsia	7.2 (2.5)	3.0 (1.7)	4.0 (3.5)	2.7 (3.1)	0.	1.3 (2.3)		
Encrusting Corallines	11.8 (10.1)	5.8 (4.6)	20.0 (9.8)	10.5 (5.4)	5.3 (4.2)	3.7 (0.6)		
Chthamalus	1.0 (1.7)	2.0 (1.7)	0.3 (0.6)	0.	1.8 (1.9)	0.		
Tegula	0.7 (1.2)	7.3 (11.0)	9.7 (13.4)	0.3 (0.6)	0.	0.3 (0.6)		
Ophiuroids	0.3 (0.6)	2.7 (2.5)	10.0 (0)	36.7 (23.1)	0.	0.3 (0.6)		
Pagurus	11.7 (12.6)	43.3 (11.5)	16.7 (28.9)	36.7 (23.1)	13.3 (11.5)	30.0 (17.3)		
Alia	0.	1.7 (2.9)	1.7 (2.9)	0.	3.3 (5.8)	10.0 (13.2)		
T. scutum	3.7 (3.2)	10.3 (8.4)	5.0 (8.7)	0.7 (1.2)	4.3 (3.2)	0.		
Lirularia	0.	0.	3.3 (5.8)	20.0 (26.5)	0.	0.		
Lacuna	3.3 (5.8)	25.0 (25.0)	6.7 (11.5)	0.	40.0 (17.3)	23.3 (25.2)		
Petrolisthes	0.3 (0.6)	16.7 (28.9)	16.7 (28.9)	16.7 (28.9)	4.3 (5.1)	0.		
Lepidochitona	0.	3.0 (2.6)	1.7 (2.9)	1.7 (1.5)	3.0 (2.0)	0.		
Leptasterias	0.6 (1.2)	2.7 (3.1)	2.0 (1.7)	0.	0.3 (0.6)	0.		
Phascolosoma	1.0 (1.0)	6.7 (11.5)	0.	0.	1.0 (1.7)	0.7 (1.2)		
Holes	3.7 (3.8)	0.	0.3 (0.6)	2.0 (2.0)	0.	0.3 (0.6)		

Table 20, cont'd.

	Oiled		Unoiled				Statistics	
	NMII	SPC	NMI	CAC	CPC	KBC	S	I
Algal canopy	21.7 (33.2)	14.7 (14.2)	9.0 (15.6)	29.7 (15.0)	58.0 (18.1)	10.7 (5.5)		
Crusts	22.3 (58)	22.8 (8.1)	26.0 (14.0)	15.2 (4.8)	13.3 (14.5)	5.0 (1.7)		
Small snails	4.0 (5.3)	34.0 (23.5)	21.3 (10.0)	20.3 (26.3)	43.3 (11.5)	33.7 (36.4)		
Grazers	3.7 (3.2)	13.3 (5.8)	6.7 (11.5)	2.3 (2.1)	7.3 (1.5)	0.		

Table 21. Abundances of common species (summer 1989) at Cobble Level 8. Significant differences are given for a Site Effect (S) and Treatment Effect (T), from ANOVAs, excluding site KBC (see text). No level 8 was sampled at Chilean Point. NMII= Norwegian Memorial II, SPC= Sand Point Cobble, NMI= Norwegian Memorial I, CAC= Cape Alava Cobble, and KBC= Kayostla Beach Cobble.

	Oiled			Unoiled		Statistics	
	NMII	SPC	NMI	CAC	KBC	S	I
Phyllospadix	0.	11.7 (20.2)	0.	5.5 (5.9)	88.3 (16.1)		
Egregia	0.	7.33 (4.62)	0.	0.	0.	•	•
Alaria	0.	20.4 (26.9)	0.	0.	0.		
Odonthalia	29.0 (19.3)	17.0 (24.4)	3.3 (5.8)	5.3 (4.2)	5.7 (8.1)		
Dilsea	6.0 (7.9)	1.3 (2.3)	0.3 (0.6)	0.	3.7 (2.1)		
Prionitis	5.7 (8.1)	16.3 (16.9)	1.3 (2.3)	0.3 (0.3)	0.		
Mastocarpus	1.3 (2.3)	2.7 (4.6)	12.0 (9.8)	0.	1.0 (0.9)		
Laurencia	2.3 (0.6)	5.7 (5.7)	7.3 (5.0)	1.0 (1.7)	0.2 (0.3)		
Gastroclonium	17.3 (20.5)	6.7 (11.5)	25.3 (24.5)	22.3 (19.1)	0.		
Iridaea	6.7 (1.2)	9.0 (5.6)	22.7 (16.2)	0.	3.0 (4.4)	•	
Neorhodomela	5.0 (8.7)	0.	0.	5.7 (8.1)	4.5 (3.8)		
Hildenbrandia	0.	3.5 (4.1)	4.8 (5.0)	5.3 (1.2)	0.7 (1.2)		
Ralfsia	0.	0.	4.2 (3.2)	0.7 (1.2)	0.7 (1.2)		
Encrusting Corallines	25.0 (5.0)	45.0 (13.2)	18.3 (8.5)	8.7 (3.1)	4.2 (6.8)		•
Erect Corallines	3.8 (4.1)	9.7 (6.8)	2.2 (1.8)	3.5 (2.6)	0.5 (0)		
Ophiuroids	1.7 (2.9)	0.	0.	36.7 (23.1)	16.7 (28.9)	•	
Pagurus	3.3 (5.8)	30.0 (17.3)	6.7 (5.8)	36.7 (23.1)	50. (0)		
Alia	33.3 (28.9)	63.3 (32.1)	0.	16.7 (28.9)	1.7 (2.9)		
T. scutum	0.7 (1.2)	0.3 (0.6)	0.3 (0.6)	1.0 (1.7)	0.3 (0.6)		
Searlesia	0.3 (0.6)	11.3 (10.3)	0.	3.3 (5.8)	0.3 (0.6)		
Linularia	0.	0.	0.	20.0 (26.4)	6.7 (11.5)		
Lacuna	25.0 (25.0)	175. (282)	6.7 (11.5)	16.7 (28.9)	3.3 (5.8)		
Tegicella	1.3 (0.6)	3.3 (3.1)	4.7 (5.0)	0.	0.		
Lepidochitona	3.0 (2.6)	1.0 (1.0)	0.7 (1.2)	1.0 (1.0)	0.		

Table 21, cont'd.

	Oiled		Unoiled			Statistics	
	NMII	SPC	NMI	CAC	KBC	S	I
Epiactis	0.3 (0.3)	0.3 (0.3)	1.0 (1.0)	0.2 (0.3)	0.		
Bittium	0.	23.3 (25.2)	0.	36.7 (23.1)	6.7 (11.6)	•	
Holes	0.7 (1.2)	0.	0.3 (0.6)	0.	0.		
Algal canopy	77.2 (18.3)	98.1 (122.7)	74.5 (14.9)	43.7 (6.5)	107. (6)	•	•
Crusts	25.0 (5.0)	48.5 (16.9)	27.3 (4.4)	14.7 (3.1)	5.5 (5.6)		
Small snails	58.3 (52.0)	262. (298)	6.7 (11.5)	90. (17)	18.3 (27.5)		
Grazers	5.0 (2.6)	4.7 (4.5)	5.7 (5.5)	2.0 (2.6)	0.3 (0.6)		

patch, about 30 cm diameter, on the lower face of a large boulder that marked the top (level 1) of the transect. In August 1989 (first sampling date at this site) the oil was about 1 mm thick; in places where it had sloughed off there was dead (white) *Hildenbrandia*. Barnacles (*Chthamalus*) in this patch had oiled sides but were still alive, and there were *Littorina scutulata* actively browsing in the oil. In July 1990 there were still some patches of now-tarry oil here, with fir needles stuck in it. Some patches of rock were still bare, but the crusts were recovering; the growth pattern of the *Hildenbrandia* suggested regrowth from remaining patches rather than recruitment.

Site-to-site differences among the cobble areas were common, obscuring treatment effects. At Levels 1 and 2 (pooled for analysis), there were site effects for only 2 species, and no treatment effects. For Levels 3 and 4, there were site effects for 13 of the 28 taxa (species and groupings), and treatment effects for 5. Three of the treatment effects can be ascribed to a high abundance of that species at a single site; this is unlikely to be a true treatment (oil) effect. "Holes" were more abundant in unoiled areas; this could be an oil effect, but is more likely due to substrate differences among sites at this level. "Snails" were slightly more abundant in oiled areas, although there were many at the unoiled NM1 site (Table 18), so this is likely a spurious correlation.

At Levels 5 and 6 there were 17 significant site effects among the 30 taxa. All three signficant treatment effects can be ascribed to large abundances of the taxon at a single site, and thus are not likely to be true oil effects. At Level 7, there were only 4 site effects out of 26 taxa, and only 1 treatment effect; for *Ulva*, there was none at the oiled sites and a moderate amount at the unoiled sites. It is possible that this is a true oil effect, although unlikely at this low level where no oil was ever observed. At Level 8 there were 5 site effects and 3 treatment effects out of 30 taxa. The kelp *Egregia* was found at only one site. The other two signficant taxa, encrusting corallines and total algal canopy, were both more abundant at "oiled" areas, perhaps because there was more bedrock at these sites at this level (Table 15).

4.3.5 Cobble Beach Structuring Processes

Substratum stability is clearly a critical structuring process on these cobble beaches. Species types and abundances differed radically between bedrock, large cobbles, small cobbles, and sediment. Portions of cobble transects that were dominated by bedrock looked very much like the protected to semi-exposed shores elsewhere, but the occasional instability of the other surfaces resulted in domination by very different plants and animals. On a smaller scale, the type of sediment (i.e. sand vs. mud, sorted vs. unsorted, amount of organic matter) probably determined the types of infauna found at a given site, although time did not allow exploration of this phenomenon in detail.

Sedimentation is an important process here relative to the rocky shores examined. The relative paucity of sessile animals such as mussels and barnacles (e.g., Fig. 22) may have been due to the instability of the substrata and to the abundant suspended sediment which clogs the filtering apparatus of suspension feeders. The subset of algae that were found in these habitats may also relate to sedimentation, since some (e.g., *Neorhodomela*) may be more sediment-tolerant than others. Clearly the presence of infauna relies on sedimentation, but otherwise this may be regarded as a harmful process.

Wave exposure affects both substratum stability and sedimentation, and thus indirectly controls organismal distributions. Since waves tended to be "broken" by the outer rocks in cobble areas, direct effects of wave action were less visible here than on rocky shores, and cobble areas can be regarded as less exposed, overall.

Another physical process that seemed to affect the biota of these cobble areas was their **retention of water**. Since the cobble transects were all extended, flat areas, tidal water drained off of them only slowly. In addition, the freshwater runoff from the land in this region contributed to keeping these transects wet, and often in flowing water. The water in the large, usually shallow pools created by these forces often was warmer than ambient (especially in the high intertidal), which likely limited the biota in them to more eurythermal species. We have no data on salinities, and thus cannot evaluate how much freshwater dilution occurred in these pools. In many pools, freshwater remained in a visibly stratified layer on the surface. We hypothesize that the presence of large, constantly wet areas allowed many low-intertidal and even subtidal species (both plant and animal) to survive in these transects (see _Unusual Species_, above).

In general, the role of biotic processes seemed overshadowed by the physical processes in these areas. **Bioturbation** of the substratum by clams, worms, and mud shrimp is likely to be an important process in aerating and turning over the sediment, as evidenced by the large numbers of holes in many of the quadrats. **Predation** is clearly important, not only by seastars and predatory snails but by the abundant intertidal fishes and by birds foraging in the shallow pools. Far more fish were seen in these transects than in the rocky shore ones; some of these are herbivorous, and some carnivorous. The role of **herbivory** is difficult to assess. Limpets and chitons were generally less abundant here than on rocky shores, presumably due to substratum instability (and perhaps also to predation). Small herbivorous snails were more abundant but are likely (with the exception of the voracious _Lacuna_) to have proportionately little impact on algal populations. Thus herbivory is probably a less critical process in these cobble habitats than on bedrock shores, although experimental evidence would be necessary to demonstrate this.

4.4 RESULTS: SANDY BEACHES

4.4.1 _Habitat Descriptions_

The high-energy sand beaches common along the Washington coastline are relatively depauperate habitats in terms of species number and primary productivity, but they do contain species of interest and play a role in nearshore ecosystems. We found a total of only 47 species (Appendix D) living in the sand at the sites sampled, although clearly other species such as birds and fish use these areas as well. There are no macroscopic plants on these beaches, as substratum instability is too high. Many of the species found are amphipod crustaceans (Appendix D)), which were sometimes found in extraordinary densities; the common genus _Eohaustorius_ occurred at up to 10,000 individuals per m^2 of surface. Polychaete and nemertean worms were also common; the bloodworm _Euzonus_ reached almost 7000 per m^2. Large flocks of western sandpipers were observed feeding in the zones of highest densities of some of these organisms, and in addition gulls and crows sometimes probed in the sand for food. At high tide, it is likely that flatfish and other fish species forage up into the intertidal zone, Also at high tide, most of the food for the infauna (drift algae and plankton) enters the system. Thus this is much more open ecosystem than the others studied.

Zonation patterns are not visible on the surface of sandy beaches, but many species in these habitats do live in relatively confined tidal levels. High on the beach, where the waves do not wet the sand regularly, there are only a few terrestrial isopods and insects, and various beach hoppers (amphipods in the family Talitridae). High beach zones that are flooded

Table 22. Characteristics of beaches with sand transects. Beaches are listed in order from coarsest sand to finest.

Ruby Beach. Coarse sand, with increasing amounts of gravel in high intertidal. High beach is steep, composed of depauperate gravel berm. Transect length = approx. 250 m.

Cedar Creek. Medium coarse sand, with steep gravel berm at top of beach. Occasional "valleys" holding water. Transect length = 180 m.

Second Beach. Medium coarse sand, with some shelly material. Occasional "valleys" holding water, or potholes. Whole beach with gentle slope. Transect length = 240 m.

Ocean Shores. Fairly fine sand low, with coarser sand mixed with shelly material in mid zones. Very fine sand high; whole beach with gentle slope. Transect length = 300 m.

Sand Point. Fine sand, with minor amounts of shelly material. Some valleys with pools. Upper part of beach more strongly sloped. Transect length = 250 m.

Kalaloch. Fine sand, with little gravel or shell material. Gentle slope throughout. Transect length = 225 m.

Figure 23 A-C. Zonation of some common sand taxa. Summer 1988 data. On this early sampling date, replicate transects were run at a number of sites: each is plotted separately. Note that levels at different sites are not necessarily at the same tidal height. Level 1 = lowest intertidal.

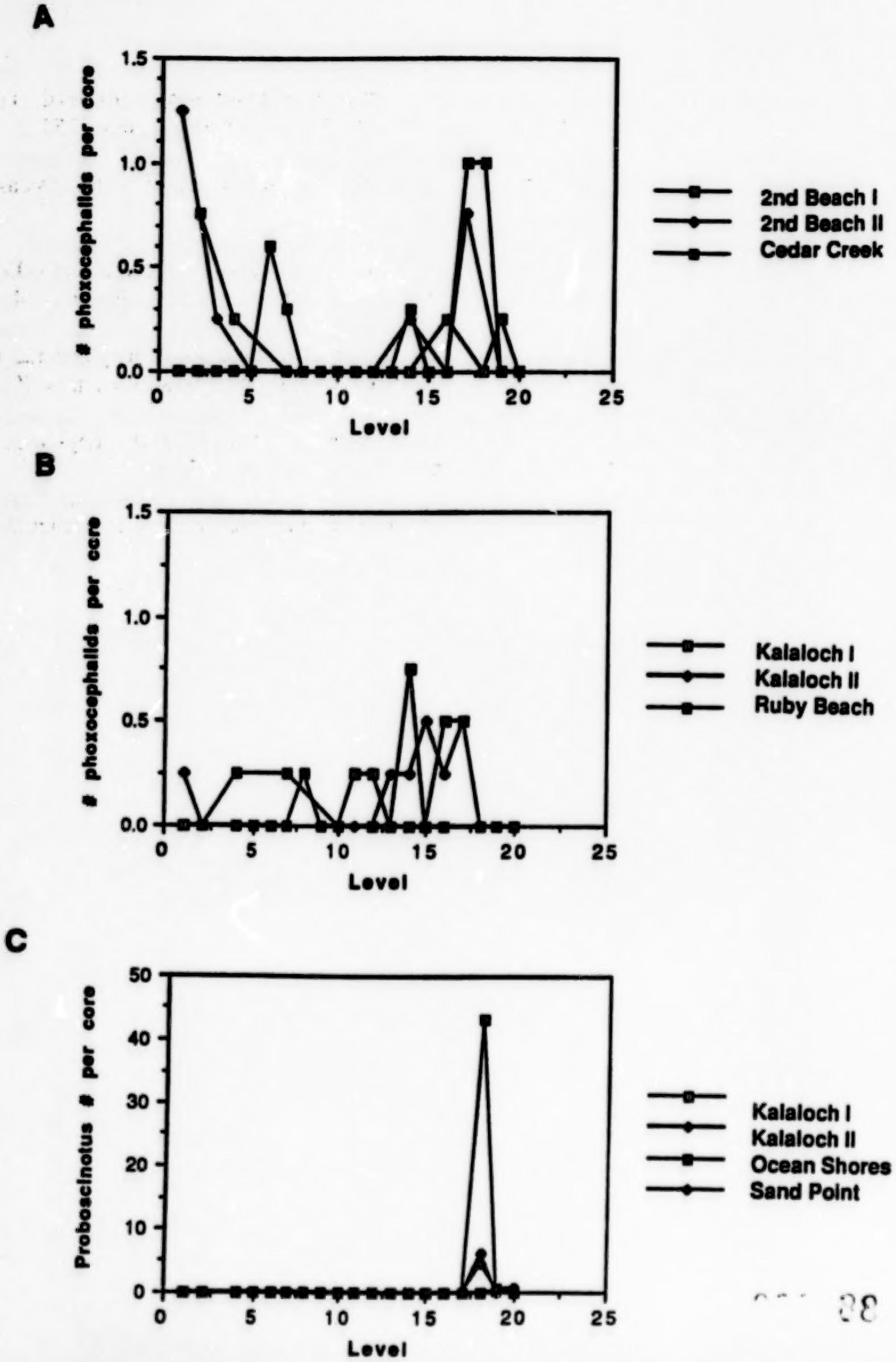
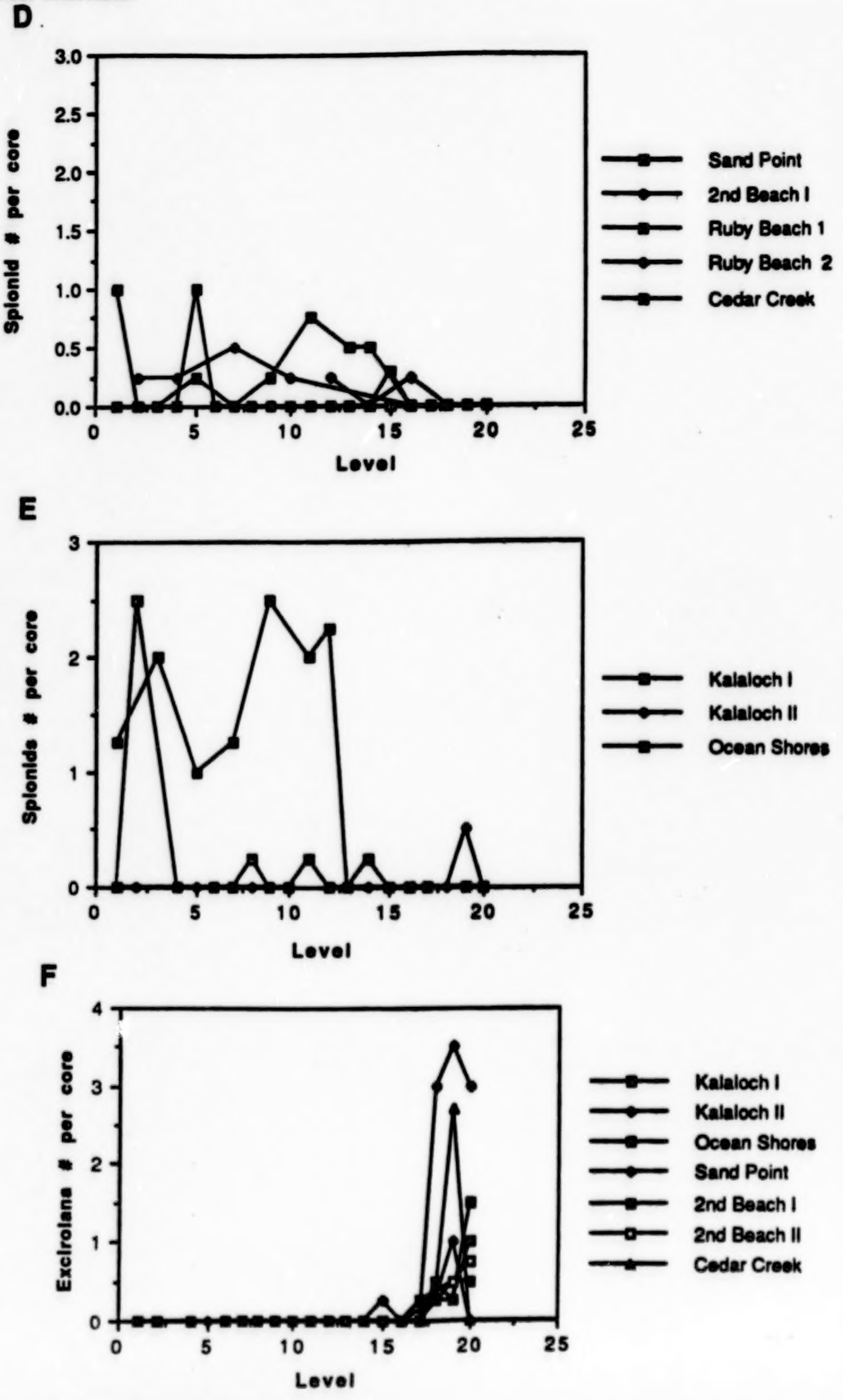


Figure 23 D-F. Zonation of some common sand taxa, Summer 1988 data. On this early sampling date, replicate transects were run at a number of sites; each is plotted separately. Note that levels at different sites are not necessarily at the same tidal height. Level 1 = lowest intertidal.



regularly are occupied in great densities by the amphipods Eohaustorius spp. (which are also found lower) and Proboscinotus loquax (which are not: Fig. 23C), by the isopods Excirolana spp. (Fig. 23F), and by the opheliid polychaete Euzonus mucronatus, which is found in a very restricted band. Proboscinotus and Euzonus are also very patchy horizontally, occuring in great numbers on some beaches but with none elsewhere. Most of the intertidal below this rich band is occupied primarily by Eohaustorius, with small numbers of nemertean and polychaete worms as well as other amphipods (mostly phoxocephalids: Fig. 23 A and B). A few species are restricted to the lowest zones; these include mysids, and the razor clam Siliqua.

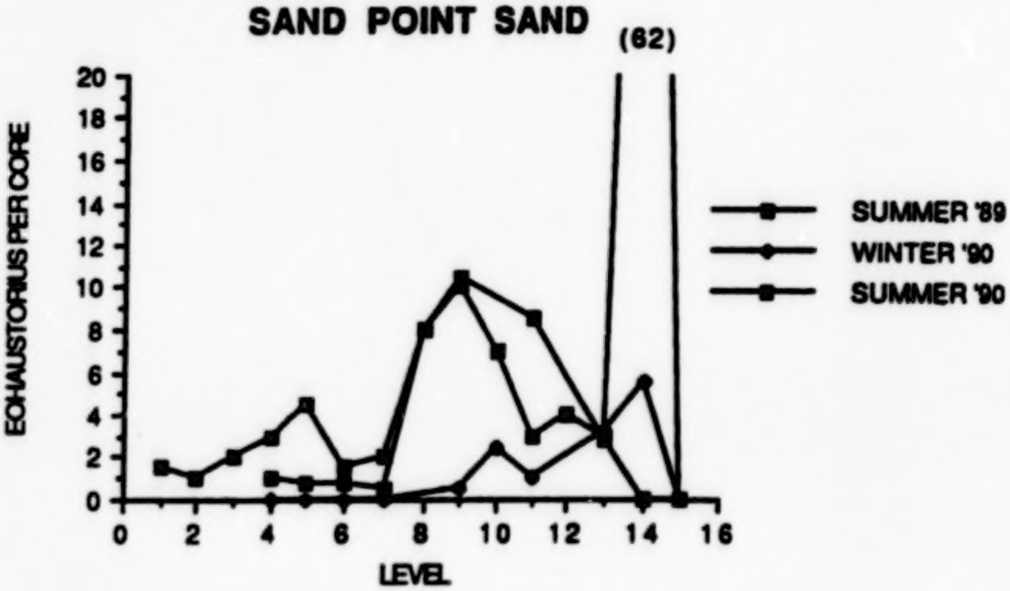
4.4.2 Site to Site and Seasonal Variation

Most of the sand-dwelling invertebrates showed striking variation in abundance both among sites and among dates within a site. Site variation may relate to substratum coarseness, to subtle differences in wave action, to beach slope, or to other physical differences that we were not able to measure. Table 22 lists subjective observations of sand composition and beach slope at the transect sites. Ruby Beach had the coarsest substratum, with the higher levels especially being dominated by small pebbles that would not pass through a 7 mm screen. Kalaloch had the finest substratum, with little gravel or shell at any level. Peak abundances of some organisms do appear to relate to this variable (see Appendix D). Euzonus was found in transects only at Kalaloch and Sand Point, two of the finest sand areas. However, some Euzonus were seen in a partial transect done at Kayostla Beach, where the sand was quite coarse. The amphipod Proboscinotus was also found only at Kalaloch and Sand Point, with a few seen on one date at the other fairly fine-sand site, Ocean Shores. This species is at the northern limit of its geographic range (Hughes 1982), which may contribute to its patchy and rather unpredictable abundance. Razor clams were common only in the fine-sand areas. The isopods Excirolana spp. were found at all sites except the coarsest one, Ruby Beach. Other distribution patterns are harder to understand: nephtyid polychaetes were fairly common at all sites but were absent from Sand Point, and phoxocephalid amphipods were found primarily at three sites differing considerably in substratum type (Fig. 23, 27). The predatory gastropod Olivella was abundant in transects only at Sand Point and Ocean Shores; in each case (and elsewhere along the coast) this species seems to inhabit sand in close proximity to rocky outcrops.

Seasonal patterns are more elusive. Zonation patterns and date-to-date abundance patterns of some of the more common taxa are illustrated in Figures 24-30. Figures 24-26 show abundances of the most common genus, Eohaustorius. Since we were not able to distinguish the 4+ local species in the field, some of the patterns here may be due not to changes in the abundance of one species, but variation in the abundances of several. In general, these amphipods were most abundant in the higher intertidal, although the Cedar Creek and Ocean Shores sites were exceptions. Often there was a dramatic peak in abundance in the highest stations, before they disappeared altogether. Abundances were clearly lower in winter at the Sand Point, Ruby Beach, and Ocean Shores sites, but not at the other three. Great year to year variation is also apparent, especially at Ocean Shores where many were found on the first date, and almost none thereafter.

Phoxocephalid amphipods (species listed in Appendix D) were never common, and showed variable zonation patterns (Fig. 27). At many but not all sites they were most abundant in the mid intertidal. The scant seasonal data suggest that they, too, are less abundant in the winter than in the summer. The striped amphipod Proboscinotus (Fig. 28A), only present predictably at Kalaloch, was more abundant in the one winter sampling than during the 3 summer samplings, but these data are scant and variability was extremely high (see Table 23 for summer 1989 variances). The isopods Excirolana spp. were

Figure 24. Abundances of the common amphipods Eohaustorius at two sites, sampling dates, and tidal levels. Level 1 = lowest intertidal. An attempt was made to set levels equal to one another from one date to the next. The Summer 1989 sample at Sand Point was done non-quantitatively, via shovelfuls rather than cores of sand.



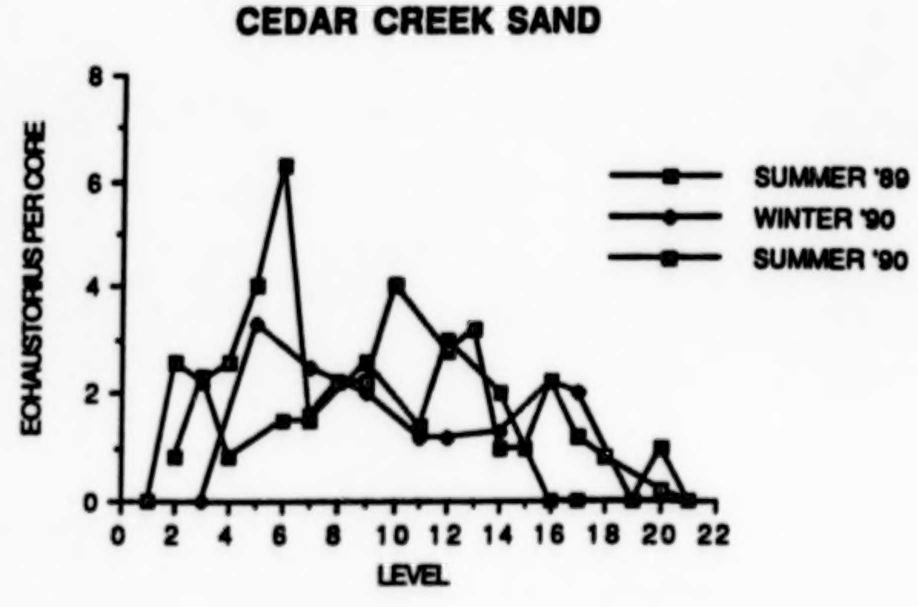
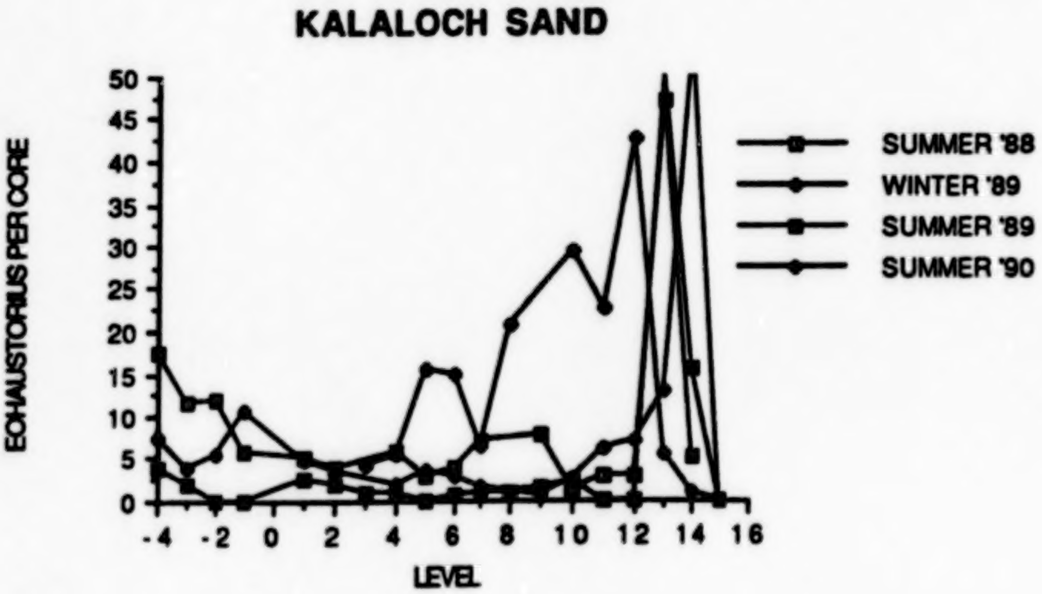


Figure 25. Abundances of the common amphipods Eohaustorius at two sites, sampling dates, and tidal levels. Level 1 = lowest intertidal. An attempt was made to set levels equal to one another from one date to the next. The winter 1989 sample at Kalaloch was done non-quantitatively, via shovelfuls rather than cores of sand.



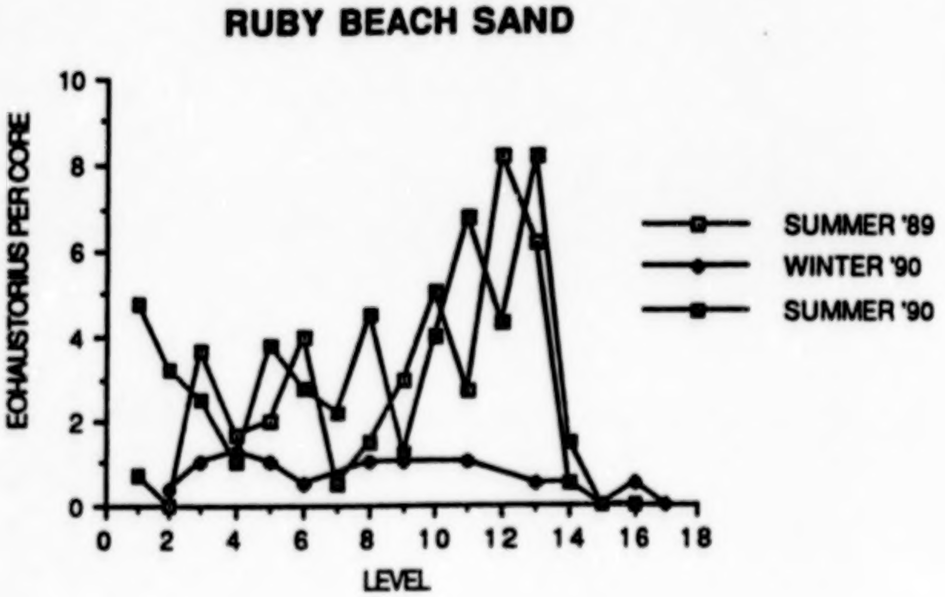
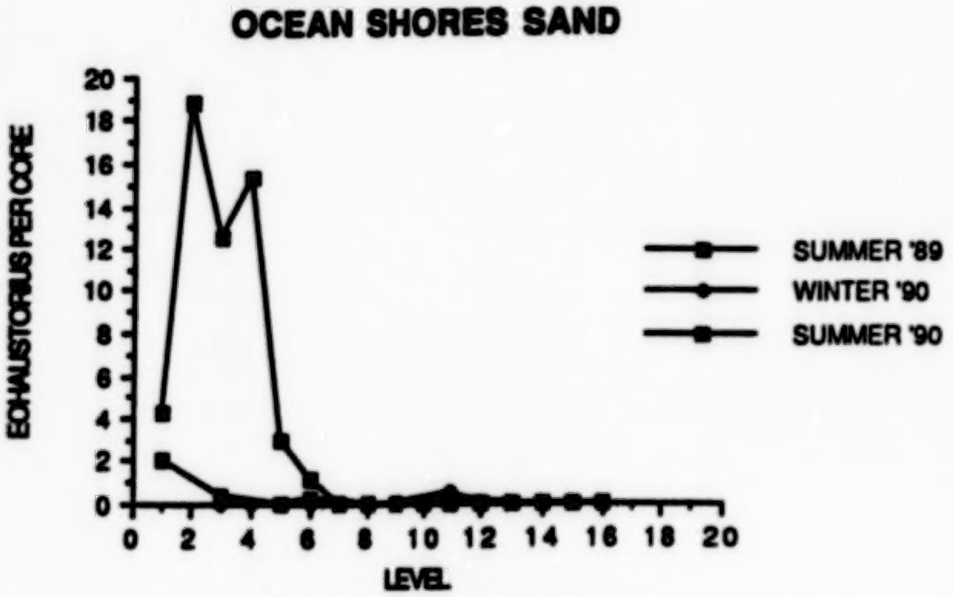


Figure 26. Abundances of the common amphipods Eohaustorius at two sites, sampling dates, and tidal levels. Level 1 = lowest intertidal. An attempt was made to set levels equal to one another from one date to the next.



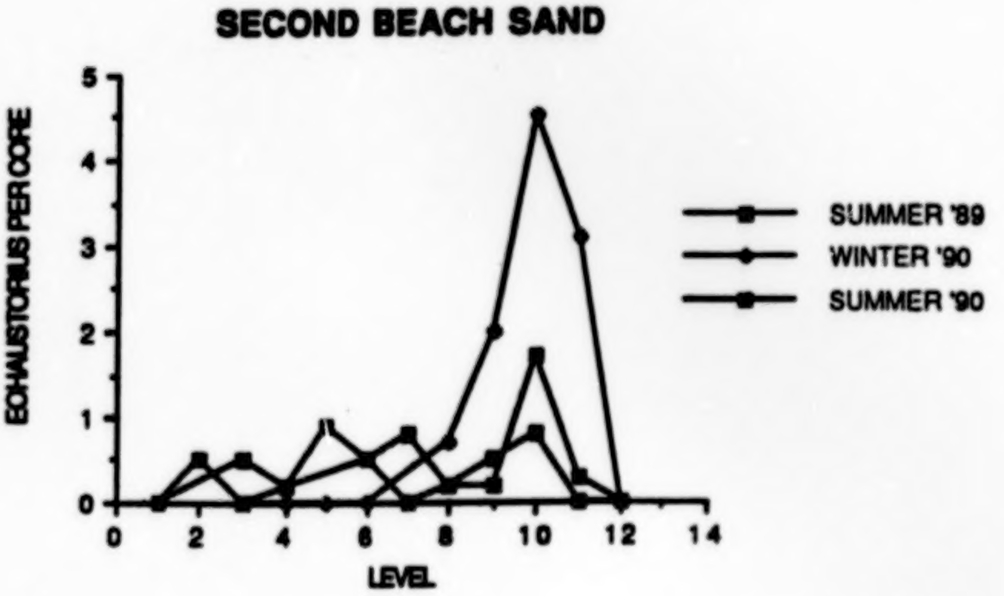
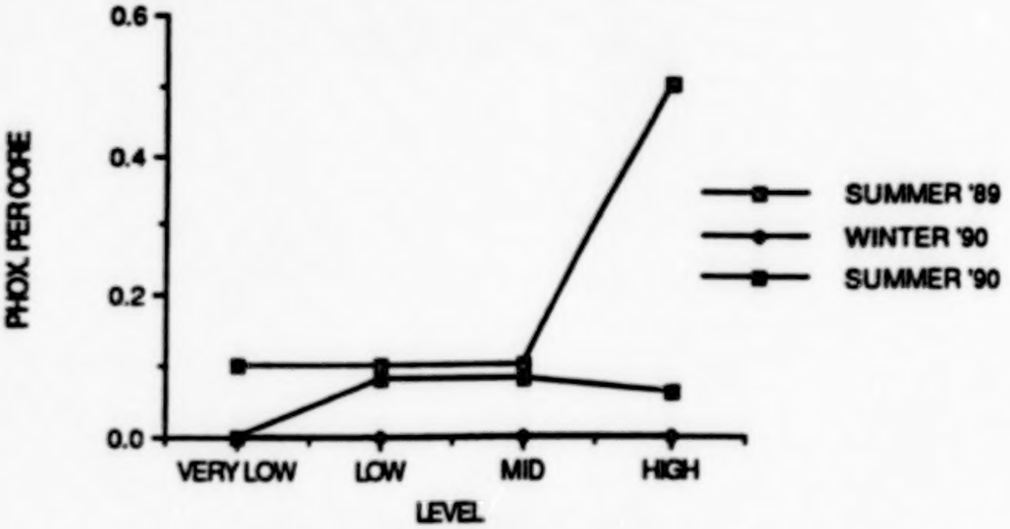
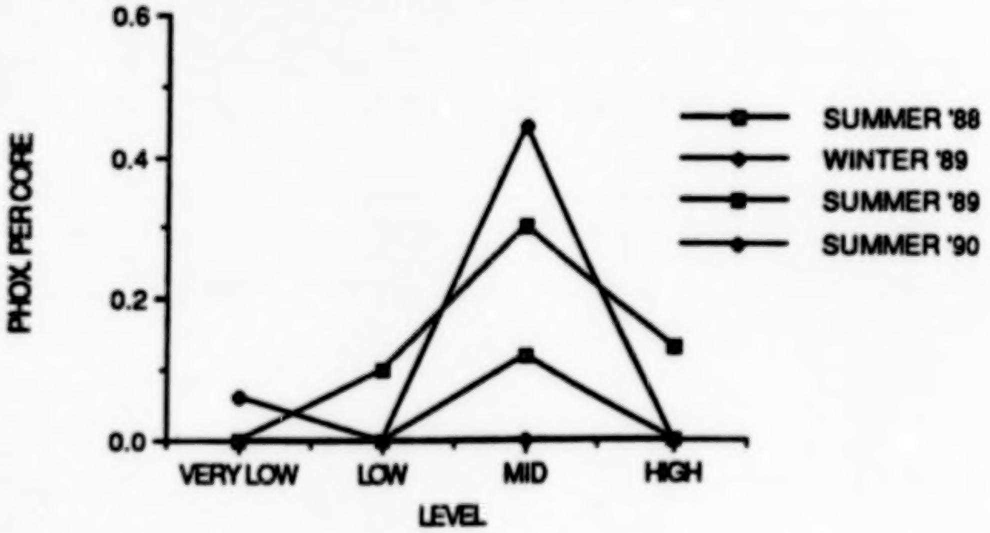


Figure 27. Abundances of phoxocephalid amphipods at all sampling dates and tidal levels. Adjacent sampling stations were lumped into broad tidal levels for analysis (see Methods). These amphipods were rare at the other sites.

PHOXOCEPHALIDS: CEDAR CREEK



PHOXOCEPHALIDS: KALALOCH



PHOXOCEPHALIDS: SECOND BEACH

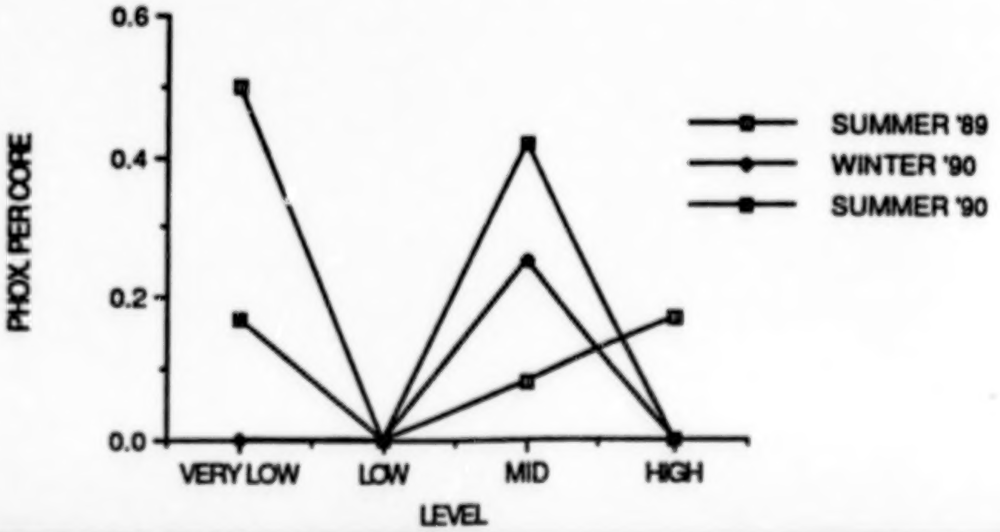
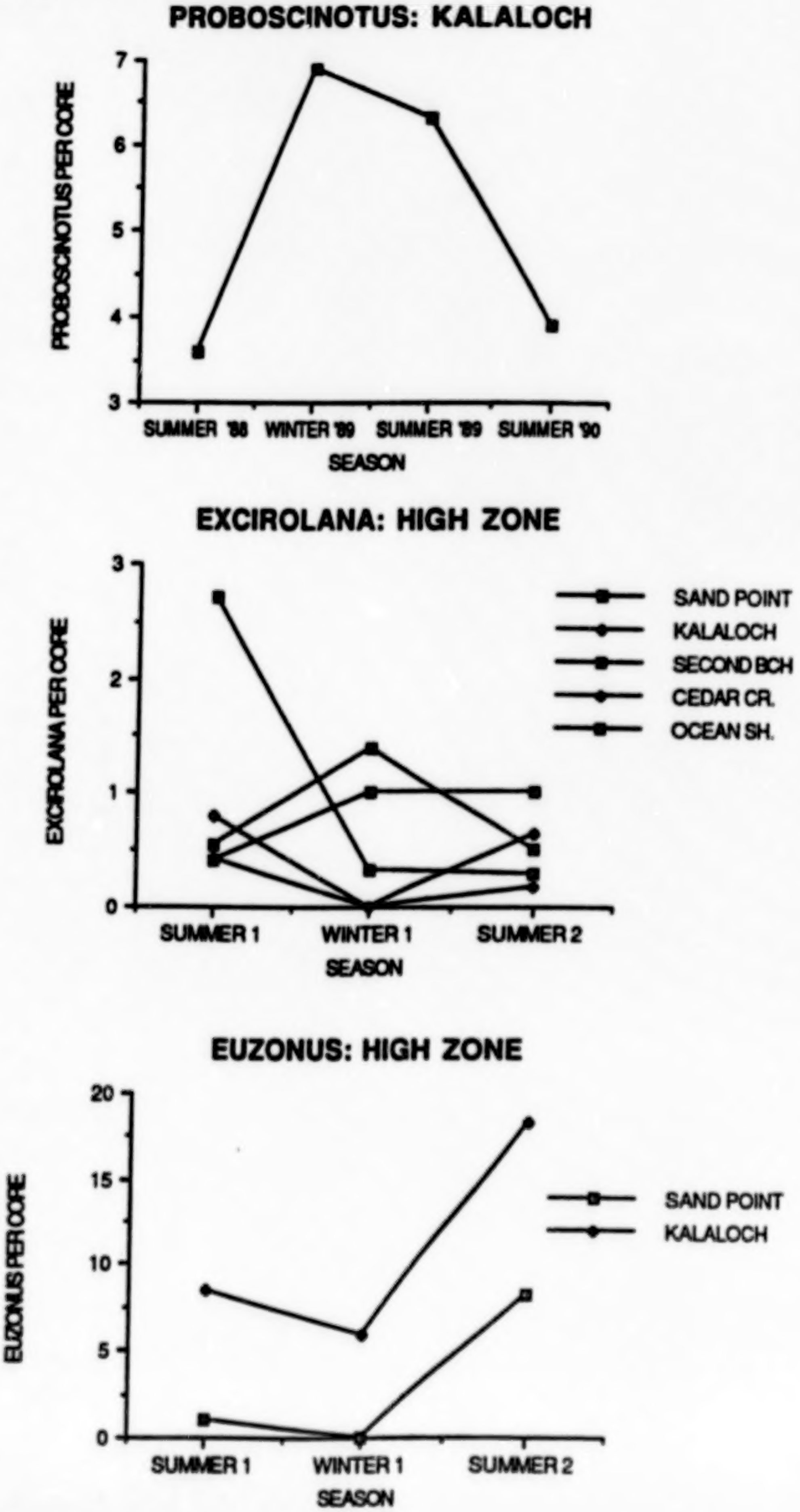


Figure 28. Seasonal patterns in three sand-dwelling genera: the amphipod Proboscinotus (common only at Kalaloch), the isopods Excirolana spp. (present at most sites), and the polychaete Euzonus (present only at two sites).

FIG. 28



less abundant in winter than summer at 3 sites, but more abundant at two sites (Fig. 28B). The polychaete Euzonus was less abundant in winter at the two sites where it was found (Fig. 28C). Lastly, nephtyid polychaetes (Fig. 29-30) showed a tendency to be more abundant in lower zones, but no seasonal pattern was evident. Thus overall there was a tendency for many of these common invertebrates to be less abundant intertidally in the winter; they may be washed out of the sand or deliberately move subtidally during the higher wave energies of this season.

4.4.3 Impacts of the Oil Spill

Tables 23 and 24 give the abundances by tidal level of the most common taxa in the sand transects during the Summer 1989 sampling (when oil impact should have been most evident), and list the significant site and treatment (oil) effects. The Very High zone contained only talitrid amphipods (beach hoppers), which showed high site-to-site variation. These were abundant at most sites, found largely under drift logs and algae, but rare in most cores except at Cedar Creek; this difference may have to do with local dampness of the sand or depth of burial of the amphipods, and is unlikely to be a real oil effect. The absence of talitrids at Ocean Shores (true through summer 1990) is odd; even turning over drift algae revealed very few. It is possible that they were killed by oil here, although after 1.5 years the populatiom might have been expected to recover. They may be negatively influenced by the freshwater outflow from Grays Harbor, or by the vehicles that are allowed to drive along the beach at this site.

In the High zone, 6 of 10 taxa showed significant site differences, again emphasizing the differences among these superficially similar areas. The only treatment effect was in Euzonus, which was found only at Kalaloch; as described above, this is more likely to be a substrate difference than an oil difference. Eohaustorius were rare at both oiled sites (Table 24), although the great patchiness precluded a signficant Treatment effect; it is possible that these were negatively influenced by oil, since small crustaceans are highly susceptible to toxic oil fractions. The Second Beach site had more amphipods in later samplings (Fig. 26), but the high zones at Ocean Shores remained depauperate through summer 1990. A non-quantitative sampling at a site down the beach from the permanent transect on Second Beach on Jan. 8, 1989 (as the oil was being cleaned up) revealed apparently healthy Eohaustorius in the sand and talitrids under oiled logs; thus we cannot definitively ascribe any patterns seen to oil damage.

In the Mid zone (Table 24), 2 of 7 taxa showed site effects, and these same 2 taxa showed treatment effects. Eohaustorius again was less abundant at the oiled sites. Spionid polychaetes were more abundant at the oiled sites, but only because of their high numbers at Ocean Shores. No spionids were recorded at Ocean Shores in Summer 1990; the 1989 worms may have been misidentified, or there may have been a real change in fauna between these dates. In the Low zone the only significant difference was again in the spionids, and may again be artifactual.

In the Very Low zone (Table 24) the same 2 of 7 taxa showed both site and treatment effects. At this level, the Eohaustorius were more abundant at the oiled sites, especially at Ocean Shores. These large numbers were not seen again after Summer 1989 (Fig. 26). Thus both these Treatment effects are likely to be spurious.

Figure 29. Abundances of nephtyid polychaetes at three sites, at all sampling dates and tidal levels.

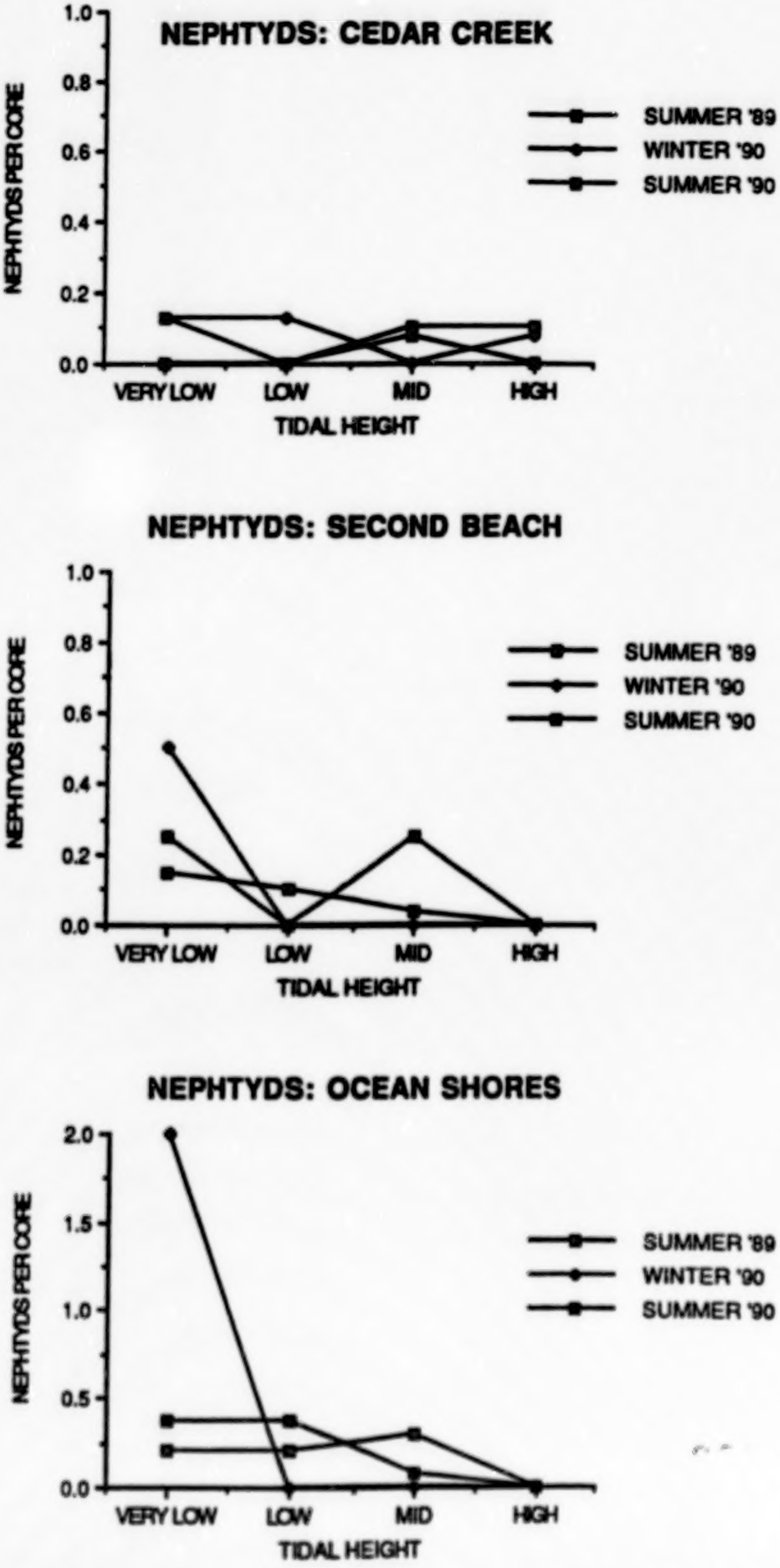


Figure 30. Abundances of nephtyid polychaetes at two sites, at all sampling dates and tidal levels.

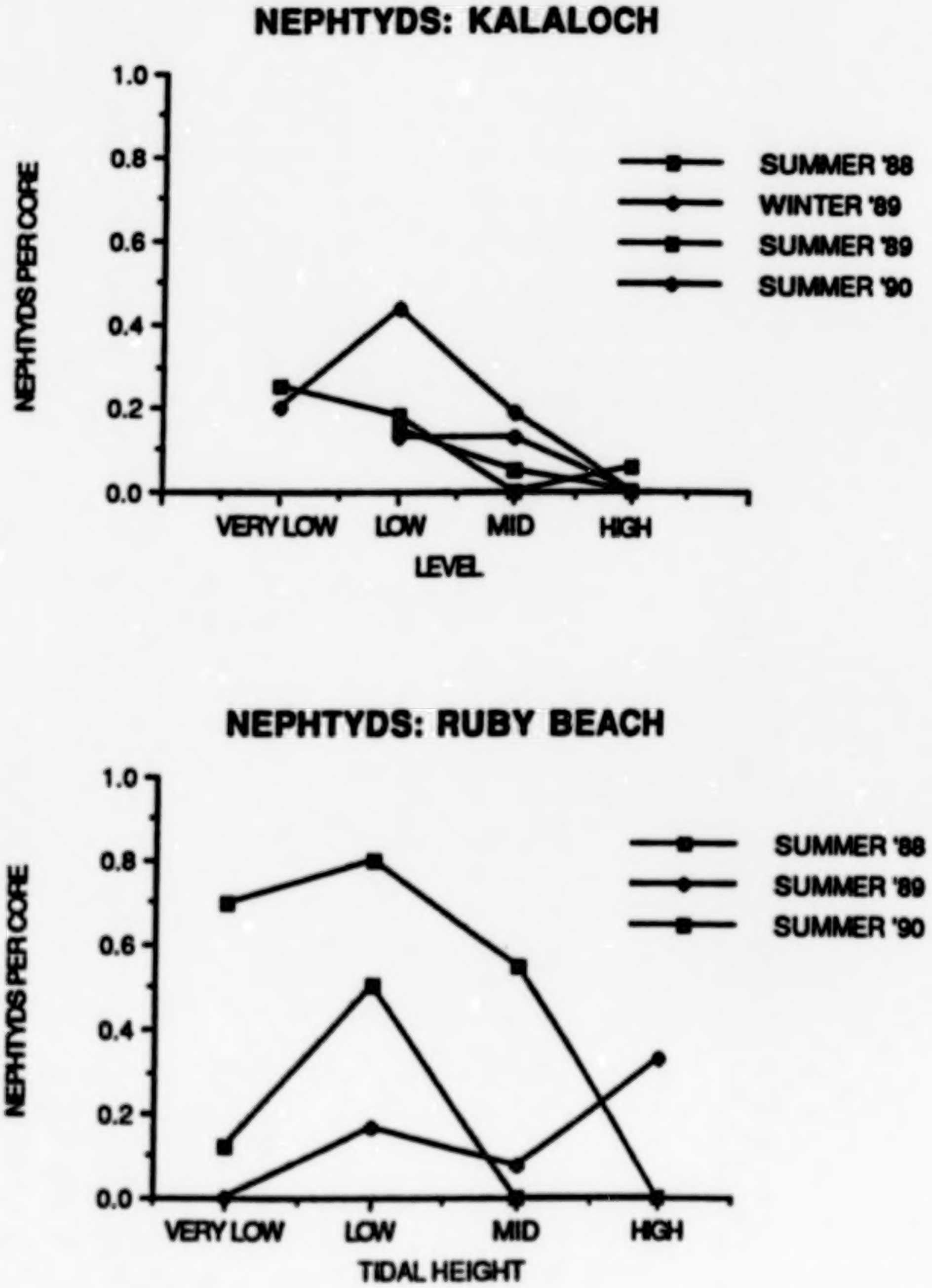


Table 23. Mean (and one s.d.) abundances per core of common species (summer 1989) at Sand sites for **Very High** and **High** levels. Significant differences are given for a Site Effect (S) and Treatment Effect (T), from ANOVAs. "Pooled" refers to the fact that 2 transects were done at several sites during this initial sampling. KCS= Kalaloch Campground Sand, RBS= Ruby Beach Sand, CCS= Cedar Creek Sand, 2BS= Second Beach Sand, and OSS= Ocean Shores Sand.

	Unoiled			**Oiled**		**Statistics**	
	KCS(pooled)	RBS(pooled)	CCS	2BS (pooled)	OSS	S	T
VERY HIGH							
Talitridae	**0.5 (0.6)**	**0.**	**7.7 (6.7)**	**1.0 (1.4)**	**0.**	•	•
HIGH							
Eohaustorius	**18.0 (26.0)**	**0.4 (0.9)**	**0.7 (0.9)**	**0.6 (1.2)**	**0.**	•	
Proboscinotus	**6.3 (17.2)**	**0.**	**0.**	**0.**	**0.1 (0.3)**	•	
Phoxocephalidae	**0.1 (0.3)**	**0.**	**0.5 (0.7)**	**0.2 (0.5)**	**0.**	•	
Excirolana	**0.4 (0.7)**	**0.**	**0.8 (1.3)**	**0.5 (0.8)**	**0.4 (0.7)**		
Eteone	**0.**	**0.**	**0.**	**0.3 (0.6)**	**0.**		
Euzonus	**13.3 (18.1)**	**0.**	**0.**	**0.**	**0.**	•	•
Nemertea	**1.1 (2.8)**	**0.1 (0.2)**	**0.**	**0.**	**0.**	•	
Spionidae	**0.1 (0.4)**	**0.**	**0.**	**0.**	**0.**		
Nephtyidae	**0.**	**0.4 (0.6)**	**0.1 (0.3)**	**0.**	**0.**	•	
Unidentified Polychaetes	**0.1 (0.4)**	**0.**	**0.**	**0.**	**0.**		

Table 24. Mean abundances (and one s.d.) per core of common species (summer 1989) at Sand sites for **Mid, Low** and **Very Low** levels. Significant differences are given for a Site Effect (S) and Treatment Effect (T), from ANOVAs. "Pooled" refers to the fact that 2 transects were done at several sites during this initial sampling. KCS= Kalaloch Campground Sand, RBS= Ruby Beach Sand, CCS= Cedar Creek Sand, 2BS= Second Beach Sand, and OSS= Ocean Shores Sand.

	Unoiled			Oiled		Statistics	
	KCS(pooled)	RBS(pooled)	CCS	2BS (pooled)	OSS	S	T
MID							
Eohaustorius	1.1 (1.3)	1.4 (2.0)	2.1 (1.7)	0.8 (1.0)	0.	•	•
Phoxocephalidae	0.3 (0.6)	0.	0.1 (0.3)	0.1 (0.3)	0.		
Eteone	0.2 (0.6)	0.	0.1 (0.4)	0.	0.		
Nemertea	0.3 (0.5)	0.3 (0.6)	0.	0.2 (0.4)	0.1 (0.3)		
Spionidae	0.	0.2 (0.5)	0.1 (0.3)	0.1 (0.3)	0.8 (1.7)	•	•
Nephtyidae	0.1 (0.2)	0.	0.1 (0.3)	0.	0.3 (0.5)		
Unidentified Polychaetes	0.1 (0.3)	0.2 (0.5)	0.	0.	0.		
LOW							
Eohaustorius	1.2 (1.7)	1.0 (1.1)	2.0 (1.6)	0.6 (0.8)	6.4 (11.2)		
Phoxocephalidae	0.1 (0.3)	0.1 (0.2)	0.1 (0.3)	0.	0.		
Nemertea	0.3 (0.5)	0.3 (0.4)	0.	0.1 (0.2)	0.		
Spionidae	0.1 (0.3)	0.4 (0.6)	0.	0.	1.9 (1.0)	•	•
Nephtyidae	0.2 (0.4)	0.1 (0.3)	0.	0.1 (0.3)	0.2 (0.4)		
Unidentified Polychaetes	0.2 (0.5)	0.	0.1 (0.3)	0.	0.2 (0.4)		

Table 24, cont'd.

	Unoiled			Oiled		Statistics	
	KCS(pooled)	RBS(pooled)	CCS	2BS (pooled)	OSS	S	I
VERY LOW							
Eohaustorius	1.5 (2.2)	0.7 (0.8)	2.9 (3.2)	2.9 (3.9)	11.6 (9.3)	*	*
Phoxocephalidae	0.	0.1 (0.2)	0.1 (0.3)	0.5 (0.9)	0.		
Eteone	0.1 (0.3)	0.2 (0.7)	0.	0.	0.		
Nemertea	0.3 (0.4)	0.1 (0.2)	0.1 (0.2)	0.1 (0.3)	0.		
Spionidae	0.	0.2 (0.4)	0.3 (0.7)	0.	1.4 (1.5)	*	*
Nephtyidae	0.2 (0.4)	0.1 (0.5)	0.	0.2 (0.4)	0.2 (0.4)		
Unidentified Polychaetes	0.	0.	0.1 (0.2)	0.1 (0.3)	0.1 (0.3)		

4.4.4 Sandy Beach Structuring Processes

Wave disturbance and **substratum instability** are clearly two of the major processes driving organismal patterns on sandy beaches. Unlike rocky-shore communities, high-energy sand beaches are much more physical-process dominated than biological-process dominated (e.g., Fleischack and deFreitas 1989). Few sessile plants or animals, or even permanent tube-dwelling invertebrates, can live in these habitats where much of the substratum gets resuspended daily, and where mass movements occur during storms and seasonally. Even haustoriid amphipods, which are excellent swimmers and diggers, get washed out of the sand at high current speeds (Grant 1981). All the invertebrates found in these habitats are either rapid burrowers (e.g., the amphipods, isopods, and clams), or live deep enough in the sand to not be disturbed regularly (e.g. many of the worms). Any tubes built are clearly temporary. Similar instability, seasonal changes, and lack of tube-building infauna are seen in the sandy shallow subtidal zone (Oliver et al. 1980). Bioturbation of the sediments by the infauna (especially amphipods and polychaetes) may be significant in the narrow zone where these are dense, but in general is likely to be very minor relative to the reworking of sediments by waves (Grant 1983).

Since the instability prevents the growth of macroscopic primary producers, sand inhabitants must consume microscopic algae (primarily diatoms) in the water column or the interstitial water, detritus brought in by the waves, or each other. Biomasses are thus generally low in this low-productivity environment. An exception is the zone just below the drift line (the swash zone), where detritus concentrates, and where there was often high biomass of amphipods, isopods, and polychaetes. Similar swash zones of high abundance are seen on sandy beaches elswhere in the world. Haustoriid amphipods (e.g., *Eohaustorius*) and cirolanid isopods (e.g., *Excirolana*) both possess behaviors enabling them to maintain this zonation; haustoriids are aggregative (which also helps explain their very patchy distributions) (Dexter 1971), and cirolanids show endogenous circadian and lunar rhythms of swimming activity that help keep them in this optimal zone without being stranded above high water (Hastings 1981). Haustoriids consume detritus and microflora in interstitial water, while cirolanids are carnivorous scavengers (Hughes 1982). The other abundant high-zone occupants in this study were the amphipod *Proboscinotus*, which eats diatoms and detritus, and moves up and down with the swash zone daily and through the seasons (Hughes 1978, 1982), and the polychaete *Euzonus*, which is a detritus feeder (Kozloff 1983). The latter organism is not very mobile, and may only be able to survive the instability of this habitat by living in the high zone, where wave action is reduced in frequency and amplitude.

As discussed above, **grain size** is probably a crucial parameter in determining organismal distributions, although the details of this connection need further exploration. Finer-grained sand retains more water through capillary action than does coarse-grained, and is easier to burrow through (Nybakken 1982). The finer-grained beaches clearly had higher diversity and biomass of invertebrates; the coarse-grained Ruby Beach site was quite depauperate, and gravelly beaches on this coast are almost devoid of organisms. Grain size, in turn, is determined partly by wave action but partly by the local source of sediment and offshore topography.

Ecological patterns and processes have been examined little on sandy beaches relative to rocky shores or even mudflats (Nybakken 1982, Ambrose 1984, Wilson 1991), due to logistic constraints and the difficulties of performing manipulations. Attempted manipulations involving cages result in large cage artifacts because of hydrodynamic effects (reviewed in Wilson 1991). Thus most information on biological processes is observational. **Competition** is probably negligible in these habitats; organisms are sparse, and food is brought in with every high tide. **Predation** is probably the most important biological structuring process. There may be some predation among the infauna (e.g., phoxocephalid amphipods are predatory: Oliver et al. 1982), but the key predators on these assemblages are probably birds and fishes (e.g., Leber 1982, Wilson 1991). As mentioned above, hundreds of birds were often seen foraging on the sandy beaches, especially in the rich swash zone. The major mortality sources for Proboscinotus are thought to be predation by shorebirds and disruption by storms (Hughes 1982); in the zone of maximum amphipod abundance, up to several thousand beak probings per square meter have been counted. The major bird predators on this shore are sanderling, least sandpipers, and dunlin, although we also observed crows and gulls probing in the sand in the swash zone. In addition, predation by subtidal fishes during high tide may be important. Surf perch and starry flounder are both abundant off this coast; flounders, especially, are known to eat amphipods (Hughes 1978). Perch often consume clam siphons, and could impact the razor clams. The degree and role of such predation have been quantified in quieter mudflats and even in lower-energy sandy beaches (e.g., Ambrose 1984, Wilson 1991), but not on the high-energy sand beaches typical of this coastline.

Another natural form of mortality for some of these invertebrates may be salinity changes. While sand does provide some buffering from salinity changes (since freshwater tends to stay on the surface over the denser seawater in the sand), large freshwater inputs may affect infauna. Dexter (1971) observed a major population reduction of a haustoriid amphipod on the North Carolina coast after a large rain, and Coe (1956) showed that infaunal bivalves can be killed by heavy rains. This could provide an explanation for the low (and variable) numbers of amphipods at the Grays Harbor site; the sand transect was just north of the mouth of this large estuary, so the waters washing over the beach may occasionally be of very low salinity. Salinity changes following large rain storms could also contribute to the variation in amphipod numbers from date to date at other sites.

5.0 CONCLUSIONS

In conclusion, while the Nestucca oil spill did tremendous damage to the bird fauna of the coast of Washington (over 11,000 oiled birds were collected, most of which died: DOE 1989, Kittle 1989), its impacts on intertidal plants and animals were much less than they might have been. Fuel oils (especially when unweathered as was largely the case here) are clearly capable of having a severe impact on marine organisms; their relative lack of effect here was due to a serendipitous combination of storm conditions and high tide that drove the oil onto the shore above the zones inhabited by the great majority of intertidal species. One of the most heavily oiled sites, Norwegian Memorial, suffered minor damage to high intertidal plants and animals on cobble benches, and there may have been impact on high-shore sand fauna at other sites such as Ocean Shores and Second Beach. Despite our rather intense sampling program, however, it was very difficult to distinguish such impacts from normal year-to-year and site-to-site variation, and from the impacts of the hard freeze that closely followed the oil spill.

Freeze impacts were seen clearly in areas that received no oil, such as the rocky transects at Chilean Point. High intertidal algae underwent considerable declines in abundance, although partial recovery was evident by 1.5 years later. Species that can regrow from persistent holdfasts recovered most quickly. The mussel Mytilus californianus suffered dramatic mortality at its upper intertidal levels; in some areas the top 30 cm of the mussel zone was killed outright, and multi-layered beds of mussels lower on the shore often lost their top layer. Since this mussel recruits infrequently and grows slowly, the impact of this freeze will be visible for many years.

Normal seasonal changes were apparent in a number of species in all habitat types (rock, cobble, and sand), although these were often difficult to distinguish from the commonly high year-to-year variance. The most common pattern was for species to decline in abundance in the winter, as the storms of this period tear off biomass or wash individuals into subtidal regions.

Some site to site variance at all habitat types could be explained in terms of substratum coarseness and stability, wave action, beach slope, and other physical variables. Other causes are likely more subtle, such as presence or absence of nearby freshwater inflows, of large numbers of humans, of key predators such as oystercatchers, flocks of sanderlings, or sea otters, or of historical events (such as the February 1989 freeze) that impacted sites differentially. While the coast of Washington has areas (e.g., the rocky shore on Tatoosh Island) that are better studied than almost any other marine habitat, other habitats such as cobble benches, sandy beaches, and sand-impacted rocky areas still have received little attention. If we are to understand structuring processes in these habitats, and if we wish to be able to predict with greater accuracy the outcomes of various human-caused disturbances, I recommend that research and monitoring continue in these lesser-known habitat types.

Should there be another "spill of opportunity" along the west coast, a number of techniques should make it more possible to distinguish oil impacts from normal variation with space and time. First and most obviously, baseline data that extend over sites, seasons, and years will always provide the best means for assessing impact. Even an extensive post-spill comparison of many oiled and unoiled sites (assuming that unoiled sites can be found) will not provide adequate data, since the pre-spill condition of the oiled sites will not be known, and since site-to-site variation along the west coast is so high. Quantification of the impact to shore communities of the Exxon Valdez spill has been virtually impossible because of the absence of pre-spill data. Since this study has allowed us to set up on the coast of Washington numerous, permanent study sites encompassing the three major habitat types, it would be to the advantage of funders of research to continue to follow these sites through time, and if possible to add more sites for greater replication, so that an adequate spatial and temporal baseline exists for this coast; this is especially true if offshore oil drilling is still under consideration. Two years of data are a good start, but the existence of events such as the Feb. 1989 freeze point to the need for studies encompassing more years.

Second, apparent site variation in organismal abundances would be lower if quadrat samples were deliberately taken in the middle of the zone of a target organism, such as mussels or kelp, rather than standardizing to absolute tidal heights, as was attempted here. This would allow comparison of the abundance of target species without variance caused by samples being taken at the edge of the species' vertical range, as occasionally happened here.

Third, some would argue for sampling only target species, and increasing replication both at the quadrat and site levels, rather than doing whole-community analysis as in this study. The advantages would be increased resolution of degree of oil impact for those key species, and elimination of the need to identify and count large numbers of relatively uncommon taxa. Table 25 lists my recommendations for such target organisms for each of the three habitat types in Washington, should this procedure be followed. The main disadvantage would be that in some cases, dominant organisms such as mussels, barnacles, and kelp might not be impacted by oil (because they are hardy) but unsampled rarer species might be; confining sampling to dominant species thus might miss a significant oil effect, or underestimate the degree of oil impact. In addition, in considering recovery from oil spills it is important to take into account not only the dominant species, which might recolonize and recover quickly, but also the uncommon ones which may take longer (e.g., because of limited dispersal or small "source" populations) to return to former abundances.

Table 25. Target species recommended for intensive sampling effort if full-community studies are not performed. Species are chosen either because they are abundant in certain zones, are key space occupiers, or are consumers known to play an important role in community structure.

ROCKY SHORES	
Wave-exposed	**Description, Zone**
Eudistylia vancouveri	Gregarious tubeworm, low
Mytilus californianus and M. edulis	Mussels, mid and high
Pollicipes polymerus	Gooseneck barnacle, mid-high
Anthopleura elegantissima	Cloning anemone, mid
Nucella spp.	Dogwhelks, low-high
Pisaster ochraceus	Ochre star, low-high
Katharina tunicata	Leather chiton, low-mid
Endocladia muricata	Bushy red alga, high
Mastocarpus papillatus	Leafy red alga, mid-high
Corallina vancouveriensis	Calcified red alga, low-mid
Dilsea californica	Leafy red alga, low
Wave-protected	
Fucus spp.	Common brown alga, mid-high
Endocladia muricata	Bushy red alga, high
Mastocarpus papillatus	Leafy red alga, mid-high
Neorhodomela larix	Branched red alga, low-mid
Phaeostrophion irregulare	Leafy brown alga, low (sandy)
Lacuna spp.	Small herbivorous snail, low
COBBLE SHORES	
Fucus spp.	Common brown alga, low-high
Gelidium coulteri	Fine red alga, low-high
Phyllospadix spp.	Surfgrasses, low-mid
Odonthalia floccosa	Branched red alga, low-mid
Tegula funebralis	Turban snail, low-high
Hemigrapsus spp.	Shore crabs, mid-high
Leptasterias hexactis	6-rayed seastar, low-mid
SANDY SHORES	
Eohaustorius spp.	Burrowing amphipods, low-high
Excirolana spp.	Burrowing isopods, mid-high
Euzonus mucronatus	Bloodworm polychaete, high
total # polychaetes	Other polychaetes, low-high

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APPENDIX A.

A COMPARISON OF VISUAL VERSUS RANDOM-POINT PERCENT COVER ESTIMATIONS: "OBJECTIVE" IS NOT ALWAYS BETTER

by Megan N. Dethier, Elizabeth S. Graham, C. Sarah Cohen, and Amy T. Sewell

INTRODUCTION

This study was designed to compare the accuracy, repeatability and efficiency of two methods of percent cover estimation: visual estimation and the random point quadrat method (RPQ). The relative advantages of these methods have been debated (e.g., Greig-Smith 1964, Jones et al. 1980, Dethier 1984, Foster et al. in press), as the two methods have different strengths and weaknesses. The RPQ method consists of recording all organisms found under randomly generated points within a quadrat frame, and has three primary advantages: 1) it is objective; 2) its accuracy theoretically can be estimated based upon distributional assumptions about the populations being sampled, and 3) repeated samplings will converge on the true abundance value. The disadvantages of the RPQ method include its limited measuring accuracy with one sample (dependent upon the number of random points used), its tendency to "miss" rare species, and the time involved in employing it. The visual estimation method (in which an observer estimates percent cover of species using a quadrat frame marked off into smaller sections) has the disadvantage of being subjective and therefore producing percent cover estimates whose accuracy cannot be theoretically estimated. Repeated visual estimates will not necessarily converge on the true value. The true accuracy of this method has seldom been tested, however. A third method, involving photographing quadrats and then projecting the photographs onto a grid of points, has been compared with the random point method by Foster et al. (in press). They found that the photographic method "missed" more taxa and underestimated organismal cover relative to the random point method.

The relative accuracies of percent cover estimates produced using these three methods have not been compared for field data, since the "true" percent cover of various species is impossible to assess. Our study was designed to compare visual estimates with RPQ estimates, both in the field and the laboratory. The latter comparison overcame the problem of not knowing the true percent cover, since we used two-dimensional assemblages created on a computer, whose exact percent covers could be measured by digitizing their areas.

METHODS

Field

We compared the efficiency and repeatability of two methods of sampling the percent cover of sessile plants and animals in permanent 0.25 m^2 (50x50 cm) quadrats on a wave-exposed rocky shore in Washington. Visual estimates were made with the aid of small squares (10x10 cm each) marked off within the quadrat frame. Random points (50 per

110

quadrat) were projected onto a fine screen mesh held within a second quadrat frame. A metal rod was dropped through the appropriate coordinates on the mesh, and the organism(s) contacted by the rod recorded. Two observers (MND and CSC) sampled each of 10 permanent quadrats using each of the two methods over a period of 3 days. Five were in the very high zone, dominated by small algae, barnacles, and mussels, and the other five were in the mid zone, dominated by large mussels, gooseneck and acorn barnacles, and anemones. Since we had no way to measure which method was most accurate, i.e., which measured the "true" percent cover most effectively, we analyzed the data to see which method was most repeatable between the two observers.

Laboratory

"Intertidal quadrats" (20x25 cm) were created using Superpaint software on a MacIntosh computer. Different "computer-species" were created, and were drawn to be similar in size (relative to the quadrat frame), shape, and percent cover to the species found in the field. Species also were drawn to overlap each other, as they do in the field. Ten different quadrats (five "high-intertidal," and five "low-intertidal") having 10 to 13 species in each were made (samples in Figure 1). For each of the ten quadrats, three versions (A, B, and C) were created by rearranging the "organisms" in the quadrat so that the three versions were not readily recognizable as being identical. This enabled us to record three RPQ and three visual estimates for each quadrat (without the visual estimates being biased by the observer remembering previous estimates for a given set of organisms), and to obtain means and variances for the estimates produced by each of the methods. While three is a small number of replicates, it is not unrealistic for many field sampling programs, and the same degree of replication was used in comparing each of the methods.

The exact percent cover of each species was determined by digitizing the area covered by the species using Image (version 1.22y) software on a MacIntosh computer. RPQ estimates were produced, as in the field, using pairs of random numbers as coordinates on the quadrat frame. Points that fell on the quadrat frame itself or that already existed in the quadrat were not used. The points were marked on transparencies, with a different set of points used for each version of each quadrat. Initially, estimates were done using 50 points; 100-point RPQ estimates were produced later, by adding an additional 50 points to each transparency and re-sampling. For each point, the species directly under the point was recorded. If species overlapped beneath a point, both were recorded.

Visual estimates were performed by three different observers who used a 20x25 cm quadrat frame marked off into 4x5 cm rectangles (each representing 4% of the total quadrat area). Observer 1 (MND) made estimates for all three versions of each quadrat; quadrats were shuffled by an independent party to minimize "learning" from one version to another. Observers 2 (CSC) and 3 (ATS) estimated percent covers in version A of each quadrat only. Observer 1 was the most experienced in the use of the visual estimation technique, and had previously trained both Observers 2 and 3 in the field.

The time required to census a quadrat by each estimation method was recorded after the observers and random point counter had become familiar with the method.

Data produced were analysed using Cricket and SAS software.

RESULTS

Field

To quantify repeatability of each of the two methods, we analyzed which method showed the smallest between-observer difference for each species recorded in each quadrat (hereafter called species-occurrences). Out of 85 species-occurrences (both tidal heights pooled), the RPQ method "missed" 16 altogether. All these were less than 2% cover (according to the visual estimates), and none of the 50 random points happened to contact them. Of the remaining 69 occurrences, 42 were estimated more repeatably by the visual estimates, and 21 by the RPQ method (p=.006, sign test). Table 1 shows these data broken into less common (<10% cover) and more common species. For the less common species, the visual method is much more repeatable than the RPQ method, while for the more common species there was no significant difference. The range of values between observers for the visual method is much smaller than for the RPQ method for each data set.

We also analyzed whether either estimation method showed a consistent bias in giving high or low abundance values. Figure 2 shows that the mean of the two visual estimate values was often lower than the mean of the two RPQ values; this was the case in 52/85 species occurrences, or 52/69 if the species missed by RPQ are eliminated. There is a very strong correlation between the two mean values for the two methods (Figure 2), but the slope of the line is different from 1.0 (perfect agreement between methods). Thus either the observer estimates are usually low, or RPQ estimates are usually high relative to the undetermined "truth". The laboratory data, below, shed light on this bias.

Times required for sampling a quadrat using the two methods differed greatly with complexity of the assemblage, but were approximately 10 minutes per visual estimate and 20 minutes per RPQ method.

Laboratory

Table 2 illustrates the accuracy of the four methods, i.e., the divergence of the estimates from the digitized values, averaged over all species-occurrences. The four methods used were: 1) the RPQ method using 50 points; 2) the RPQ method using 100 points; 3) visual estimation by three observers; and 4) visual estimation by Observer 1 only. The RPQ estimates and Observer 1 estimates are means calculated from the three versions of each quadrat, while the mean from the three observers is for version A of each quadrat only. These data confirm that RPQ estimates are less accurate (greater divergence from digitized) than are visual estimates, with RPQ (50 points) being least accurate and visual estimation by Observer

1 being the most. A Kruskal-Wallis 1-way ANOVA and non-parametric multiple comparisons (SNK) performed on these differences showed that the accuracy of the two RPQ methods differed significantly from each other and from visual estimates, but that visual estimates by a single observer did not significantly differ from those by several observers.

Figures 3-23 display the means of the three percent cover estimates for each species-occurrence, sampled by the four methods. The digitized value for each species in each quadrat is also shown. The relative sizes of the error bars in Figures 3-23, and the overall standard deviations (Table 3) for each estimation method suggest that methods also differ widely in repeatability, i.e. variance among the three replicates. A Kruskal-Wallis test showed that the four methods differed significantly in among-replicate variance ($p = .0001$), and multiple comparisons indicated that each method is significantly different from the others (Table 3). Again, RPQ (50 points) was the most variable, and visual estimation by Observer 1 was the least.

Other analyses tested how well the different methods estimated the abundance of common vs. rare species. Species that covered less than 2% (digitized values) of the quadrat (156 out of 342 species-occurrences) were poorly estimated by both RPQ and visual estimation (Table 4). In the case of the RPQ method, this is because the rare species were often missed (60% of the rare species-occurrences missed by 50-point RPQ; 45% missed by 100-point RPQ). When a point did contact a rare species it usually resulted in that species being overestimated, since the lowest percent cover that could be produced by RPQ was 2% (50-point quadrats) or 1% (100-point quadrats). Visual estimation was more reliable in terms of noting rare species in each quadrat (0 missed), but most values were overestimated. This is partially a result of limited potential accuracy, as rare species were estimated by observers in previously designated increments of "trace" ($\leq$ 0.5%), 0.75%, 1% and 1.5%. Both visual methods overestimated more of the time but to a lesser degree than did both RPQ methods (Table 4).

Percent covers of more abundant species (186 out of 342 species-occurrences) were proportionately more accurately estimated by both visual estimation and RPQ techniques. For all the rare species, mean divergence from the true (digitized) mean (0.82%) ranged from 40% (Observer 1) to 145% (RPQ) of the true value, while for the more common species (digitized mean of 7.1%) the range was only 11 to 47%, respectively. The RPQ method continued to miss species with percent covers under 5% (19 of the 20 "missed" occurrences were of species <5%). Again, both methods tended to overestimate the true value more often than expected (Table 4, Figs. 3-23). The four methods differed in their frequency of overestimation (Chi-Square, $p < .02$); 50-point RPQ overestimated the least often but to the greatest degree, and Observer 1 overestimated the most often but to the smallest degree. Both sets of visual estimates had a much lower degree of overestimation than both RPQ's. The total amount of overestimation (frequency times degree) is 2-3X greater for the RPQ method than for the visual estimates. These data suggest that in the field sampling (Fig. 2), the visual estimates may have been closer to the truth than were the RPQ estimates.

The average times required to census one quadrat by the different estimation methods are shown in Table 5. Visual estimation and the 50-point RPQ method took comparable amounts of time (3 to 4 minutes each), while the 100-point RPQ took longer.

DISCUSSION

Our results suggest that visual estimation is a legitimate technique for estimating percent cover, producing data that are accurate and repeatable (not only by the same observer, but also between different observers). The RPQ method, although objective, is much less accurate than visual estimation, at least when trained observers are involved. Greig-Smith (1964) points out that even RPQ estimates have a subjective component, in deciding whether a pin of finite size (as opposed to a theoretical "point") actually touches a species. The estimates produced by the RPQ method are also more variable both in the field and the laboratory, decreasing the reliability of this method even more. Single RPQ counts often gave numbers highly different from the true value, although repeated counts converged on the truth. Since quadrats are usually sampled only once per sampling period in the field, the accuracy and reliability of a single census time is crucial in assessing the relative strengths and weaknesses of the two methods. By this criterion, the visual estimation method is better than either of the RPQ methods.

Comparing the efficiencies of the two methods suggests that visual estimation and 50-point RPQs require comparable amounts of time when using two-dimensional, computer-generated quadrats. In the field, however, the RPQ method required considerably longer than visual estimation and was more difficult to perform. When organisms are multi-layered (as is often the case), for each random point the frame must be picked up and the upper layer of plants moved aside to see the understory. With visual estimates, each layer of organisms can be estimated without moving the quadrat, and then the upper species are moved aside to sample lower layers. Visual estimation is also more effective in noting all species present in a quadrat, as rare species are often missed by the RPQ method, both in the field and in lab. The usefulness of the visual method is probably limited to relatively small areas ($\leq 1\ m^2$), since areas larger than this are more difficult to "integrate" mentally.

Increasing the number of random points used (from 50 to 100 points) significantly improves the accuracy and decreases the variability of RPQ estimates. These improvements, although substantial, still produce RPQ estimates that are significantly less accurate, more variable, and more biased towards overestimation than are visual estimates (Tables 2-4). Increasing the RPQ accuracy and variability by doubling the number of points also requires a substantial increase in sampling time. Since time is always a factor in field sampling, and especially in intertidal research, the improvements gained by increased point number must be weighed against the loss in sampling efficiency.

The RPQ method is easier to perform, since the sampler needs only to identify and record the species under the point rather than concentrating on the distributions of various species to estimate the percent covers of each. Our results show that although the visual estimation technique requires more concentration, observers who have had relatively little experience with the technique can produce estimates that are not significantly different in their accuracy from estimates performed by an experienced observer. Not surprisingly, variability among different observers was greater than within-observer variance, but both variances were still lower than with the RPQ method.

The primary advantages of the RPQ method are its (relative) objectivity and the fact that its accuracy can be theoretically estimated, making this method appealing for the purposes of statistical analysis. The visual estimation technique, being subjective, has the potential to be biased. Our study suggests that bias (notably the tendency to overestimate abundance of species with low percent covers) is similar across different observers, but also exists for the RPQ method; this may stem from an unconscious desire for a point that is only close to a species to be recorded as a "hit". Overall, the inaccuracy, variability, and bias of visual estimates was much lower than for RPQ estimates, demonstrating that observer subjectivity is a relatively small contributor of error compared to the inaccuracy inherent in RPQ sampling. Finally, all sampling variance, by whatever method, is likely to be smaller than among-quadrat variance in naturally heterogeneous assemblages. One can therefore argue that increasing sample size by using the more rapid visual technique (which our data suggest is also the better one) is highly desirable for reducing sample error, and in the end will give a more accurate representation of population abundances than will using the slower, more "objective" RPQ technique.

Table 1. Repeatability of visual and RPQ estimates in the field. Values are the mean and range of differences in estimates between the two observers, summed over all species-occurrences (per zone, and both zones pooled). Some ties occurred where both methods were equally repeatable, so the N's of the more repeatable method do not always add up to the total N species-occurrences. Sign tests were run for the pooled zones; ties were omitted.

	MID ZONE		VERY HIGH ZONE		BOTH ZONES	
	RPQ	EST.	RPQ	EST.	RPQ	EST.
RARE SPECIES (<10%)						
Mean (s.d.) diff.	3.4(3.3)	1.1(1.2)	2.6(2.0)	1.1(0.8)	3.0(2.8)	1.1(1.0)
Range of diff.	0-12	0-4	0-6	0-3	0-12	0-4
N spp-occurr.	24	24	21	21	45	45
N more repeatable	4	16	5	15	9	31
p value, sign test						.0005
ABUNDANT SPECIES (>10%)						
Mean (s.d.) diff.	7.8(8.2)	5.2(4.8)	6.7(5.9)	6.7(5.1)	7.2(7.0)	6.7(5.1)
Range of diff.	0-24	0-14	0-20	0-16	0-24	0-16
N spp-occurr.	12	12	12	12	24	24
N more repeatable	5	6	7	5	12	11
p value, sign test						.50

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Table 2: Comparison of the divergences from the true (digitized) percent cover values for each species-occurrence (all data pooled) using each of four estimation methods in the laboratory study. Means are calculated from the absolute values of the difference between the digitized value for a given species occurrence and the estimated value. Kruskal Wallis ANOVA comparing these four methods is highly significant (p=.0001). Letters in the last column are different for significantly different means.

Comparison	No. of estimates	Mean difference (s.d.)	
Digitized - 50 RPQ	342	2.3 (2.6)	A
Digitized - 100 RPQ	342	1.6 (1.9)	B
Digitized - All Observers	342	0.63 (0.68)	C
Digitized - Observer 1	342	0.56 (0.54)	C

Table 3: Comparison of the variance among replicates (N = 3 replicates per mean) using each of four estimation methods in the laboratory study. Mean standard deviations are calculated from all the standard deviations of the three replicates (versions A, B, and C) for each species-occurrence. A Kruskal-Wallis ANOVA on these standard deviations was highly significant (p = .0001). Letters in the last column are different for significantly different means.

Method	No. of Means	Mean standard deviation (s.d.)	
50-Point RPQ	114	2.6 (2.2)	A
100-Point RPQ	114	1.6 (1.4)	B
All Observers	114	0.60 (0.73)	C
Observer 1	114	0.34 (0.38)	D

Table 4: Comparison of accuracy of sampling and direction of bias for rare vs. common species, using each of four estimation methods in the laboratory study. "Rare" species = digitized value of less than 2%, "common" = greater than 2%. N = number of species occurrences per category. Each Mean = mean deviation of the estimate from the digitized value, either for total sample, for overestimated values, or for underestimated values. The latter does not include species-occurrences that were missed altogether in the RPQ method (ie. no point contacted that species). For species < 2%, each of the Observer methods also had N = 1 of complete agreement with the digitized value. Digitized values were almost always non-integers, making precise estimations unlikely.

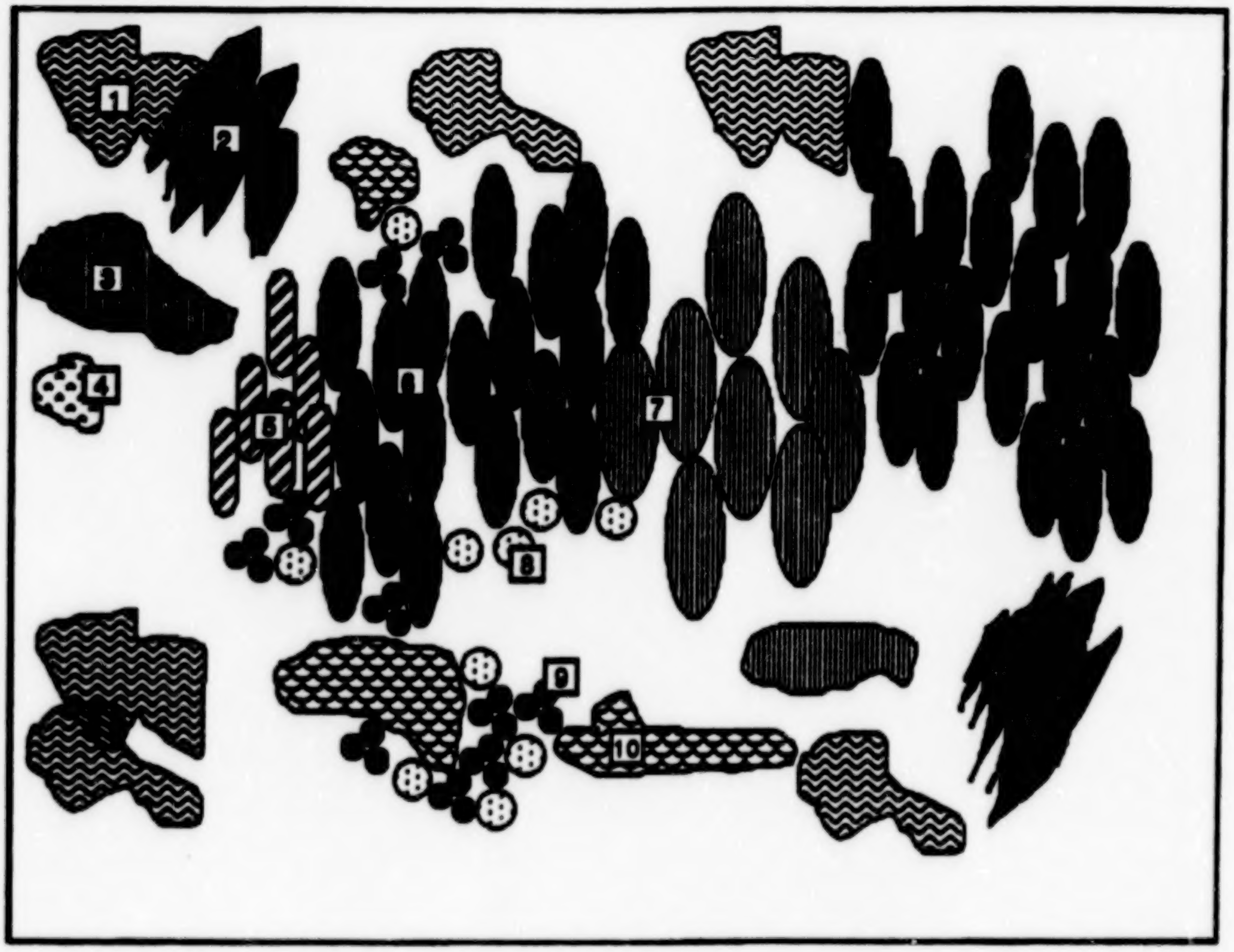
	Total Sample			Overestimations			Underestimations			Number
Comparison	N	Mean	(s.d.)	N	Mean	(s.d.)	N	Mean	(s.d.)	Missed
A. Rare Species:										
Digitized - 50 RPQ	156	1.2	(1.1)	63	1.9	(1.4)	0	--		93
Digitized - 100 RPQ	156	0.80	(0.78)	72	1.1	(1.0)	14	0.28	(0.23)	70
Digitized - All Observers	156	0.36	(0.35)	145	0.37	(0.35)	10	0.14	(0.07)	0
Digitized - Observer 1	156	0.33	(0.29)	148	0.34	(0.29)	7	0.09	(0.05)	0
B. Common Species:										
Digitized - 50 RPQ	186	3.3	(3.1)	104	4.0	(3.6)	62	2.3	(2.3)	20
Digitized - 100 RPQ	186	2.3	(2.3)	116	2.6	(2.6)	67	1.6	(1.6)	3
Digitized - All Observers	186	0.86	(0.80)	118	0.96	(0.83)	68	0.69	(0.72)	0
Digitized - Observer 1	186	0.76	(0.62)	134	0.91	(0.62)	52	0.37	(0.41)	0

Table A-4

Table 5: Comparison of time required to census a laboratory quadrat using each of the four estimation methods. Times were taken for haphazardly selected quadrats, once the counter was accustomed to that method.

Method	No. of timed events	Mean time (s.d.) in minutes
50-Point RPQ	18	3:44 (0:34)
100-Point RPQ	18	5:32 (0:32)
All Observers	16	3:07 (1:01)
Observer 1	20	2:53 (0:34)

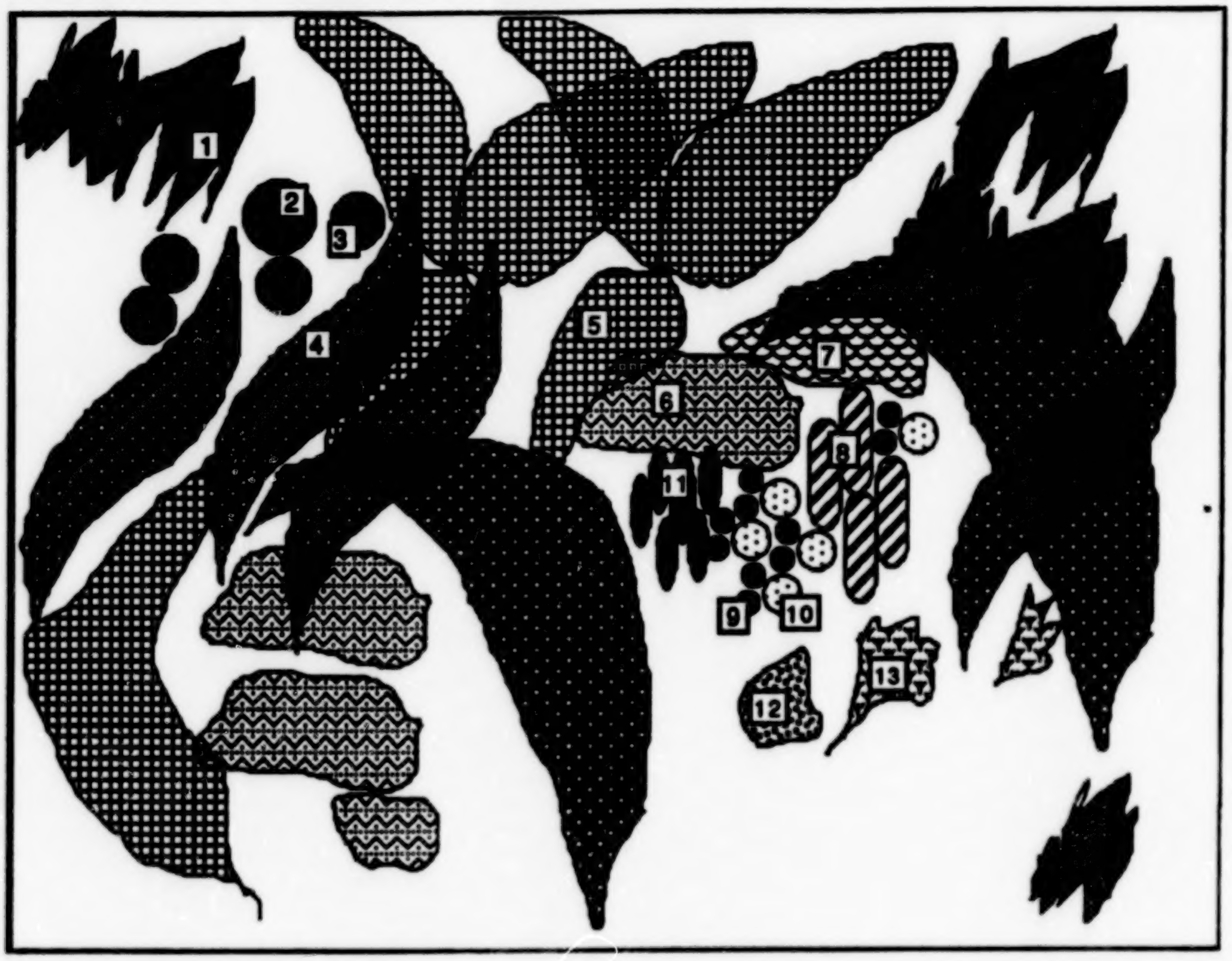
Figure A-1A. Sample "high intertidal" laboratory quadrat, showing diversity of "species", shapes, and visual complexity.



Species

1. Fucus
2. Mastocarpus
3. Crusts
4. Gelidium
5. Pollicipes
6. Mytilus edulis
7. Mytilus californianus
8. Semibalanus cariosus
9. Balanus glandula
10. Chthamalus

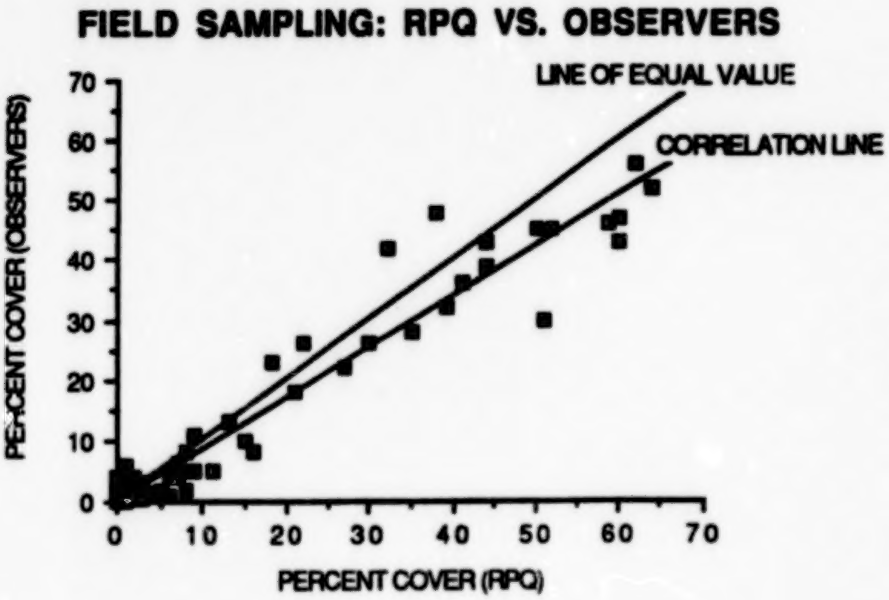
Figure A-1B. Sample "low intertidal" laboratory quadrat, showing diversity of "species, shapes, and visual complexity.



Species

1. Mastocarpus
2. Anthopleura xanthogrammica
3. Anthopleura elegantissima
4. Dilsea
5. Hedophyllum
6. Encrusting coralline algae
7. Chthamalus
8. Pollicipes
9. Balanus glandula
10. Semibalanus cariosus
11. Mytilus edulis
12. Polysiphonia
13. Microcladia

Figure A-2. Comparison of values for 85 species-occurrences in the field using RPQ and visual sampling. Each axis represents the mean of the two values produced by the two observers. Correlation line has a slope of 0.84 and r^2 of 0.94.



Figures A3 - A22. Accuracy and repeatability of four techniques for estimating the percent cover of all "species" in each quadrat in the laboratory. Bars represent either the true, digitized value, or the mean and one standard deviation value for the three estimates of each species-occurrence. Lack of an error bar indicates complete agreement among the three estimates for that value (except for the digitized value, which was only measured once). Complete species designations are given in Figure A1. Quadrats 1-5 are "high intertidal", 6-10 are "low".

Figure 3: Quadrat 1 Algae

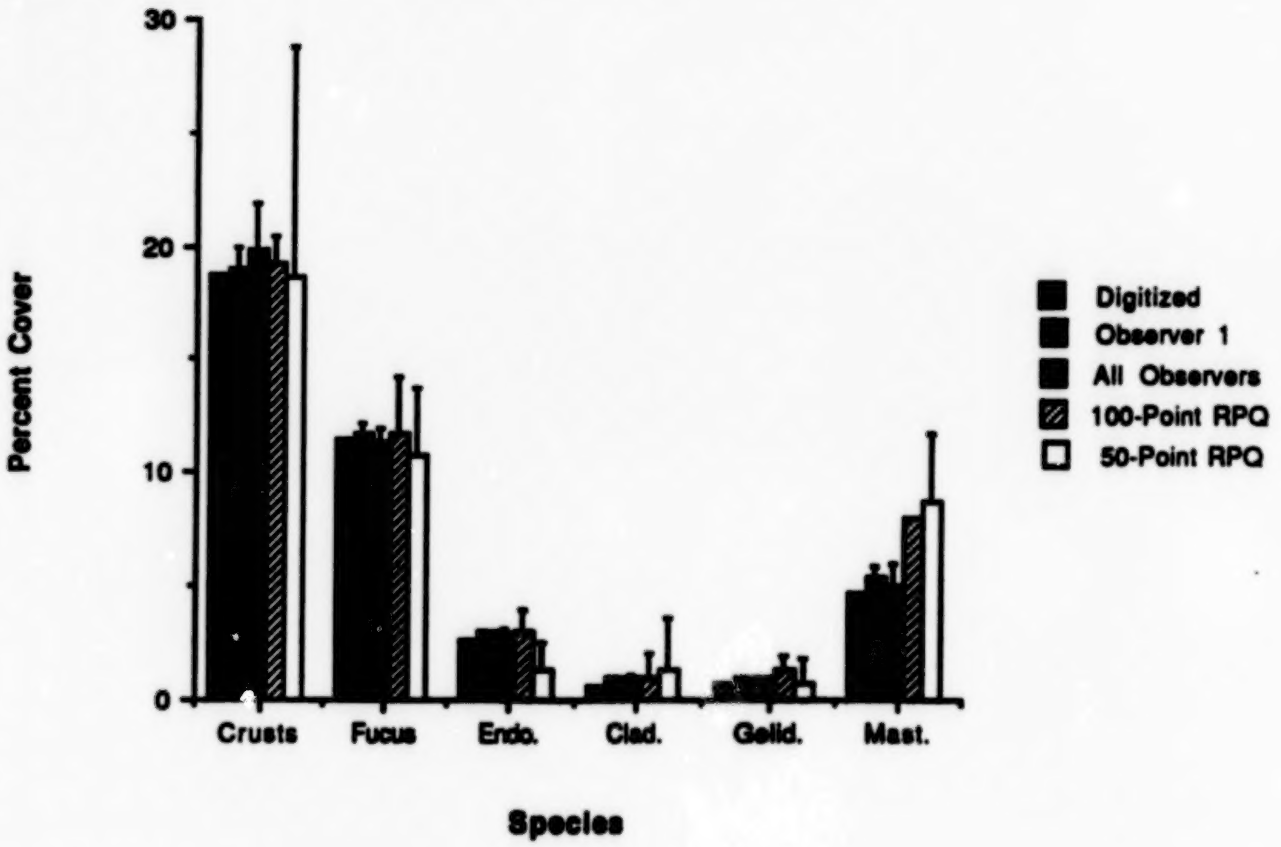


Figure 4: Quadrat 1 Animals

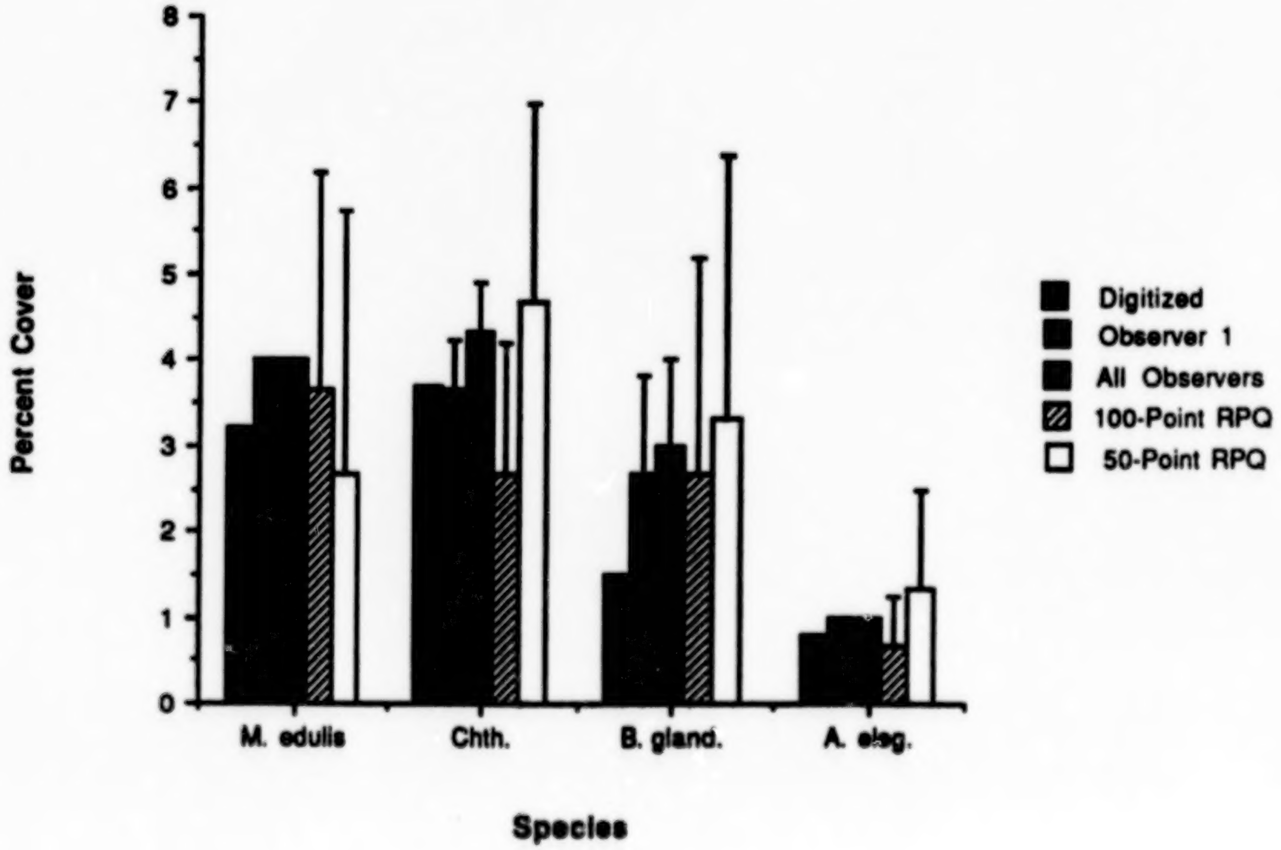


Figure 5: Quadrat 2 Algae

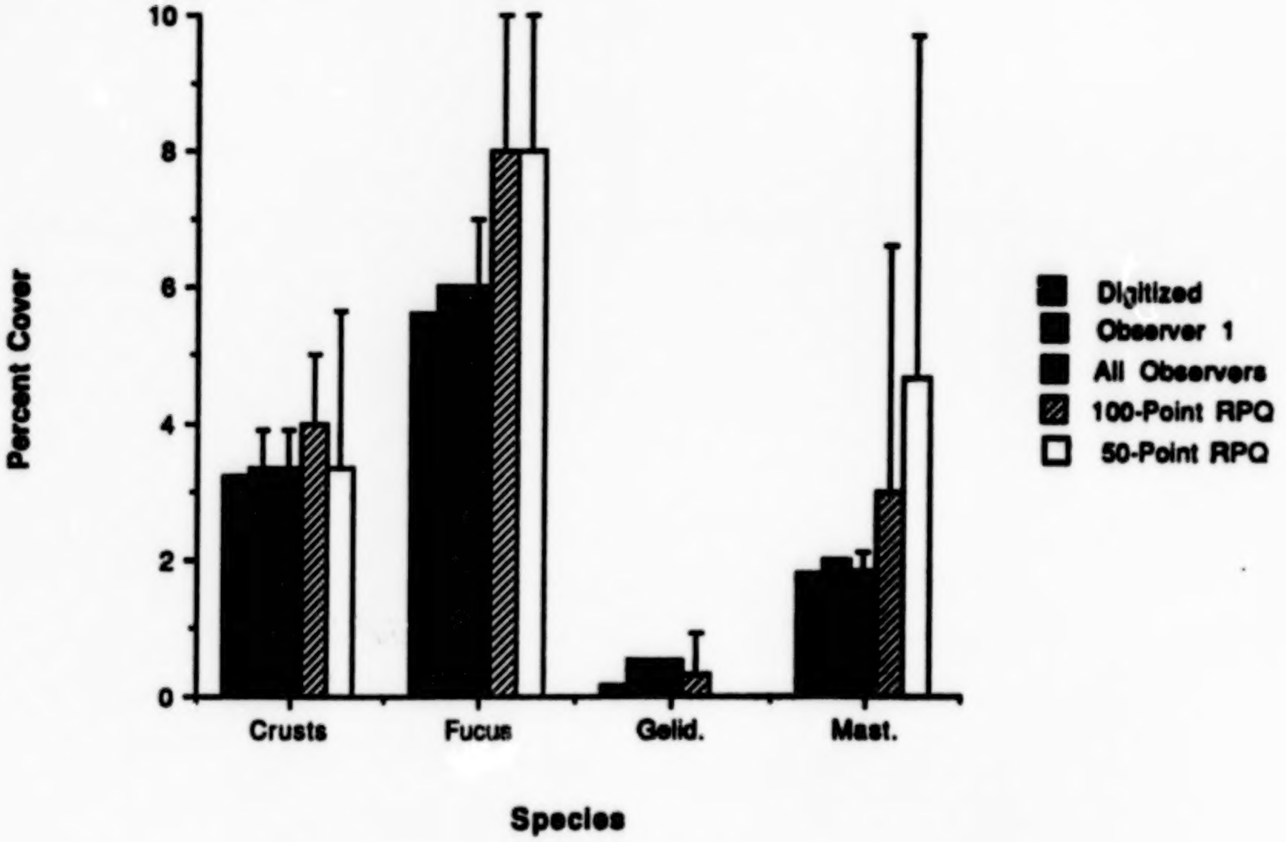


Figure 6: Quadrat 2 Animals

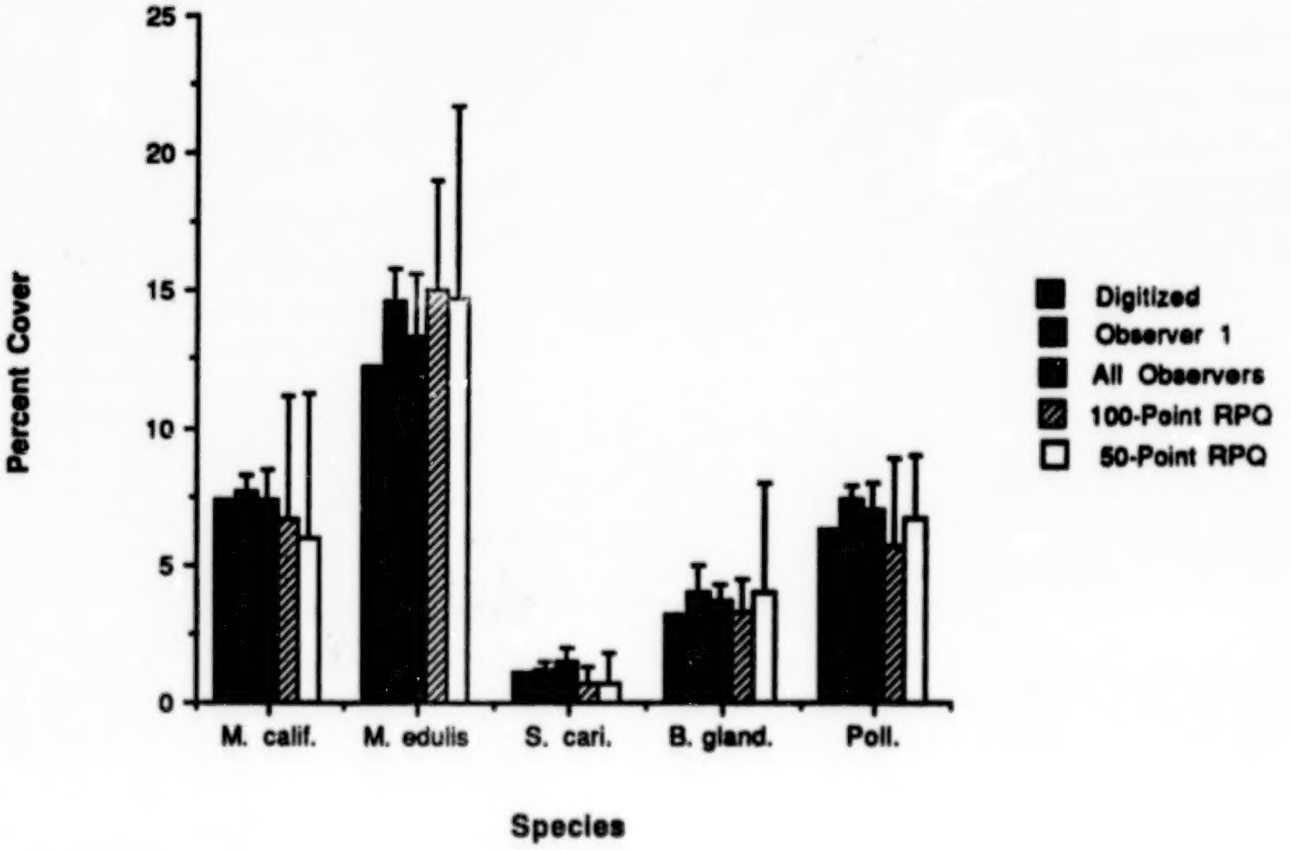


Figure 7: Quadrat 3 Algae

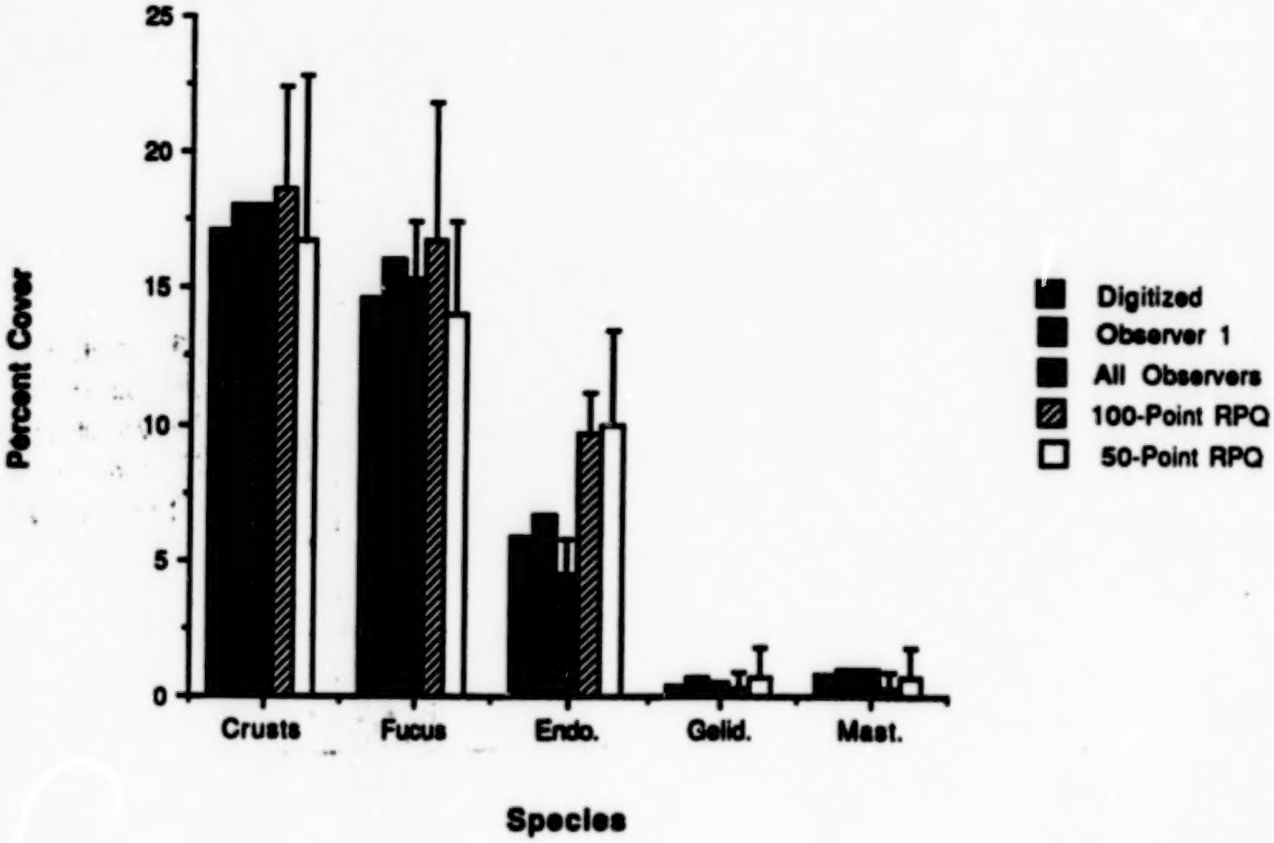


Figure 8: Quadrat 3 Animals

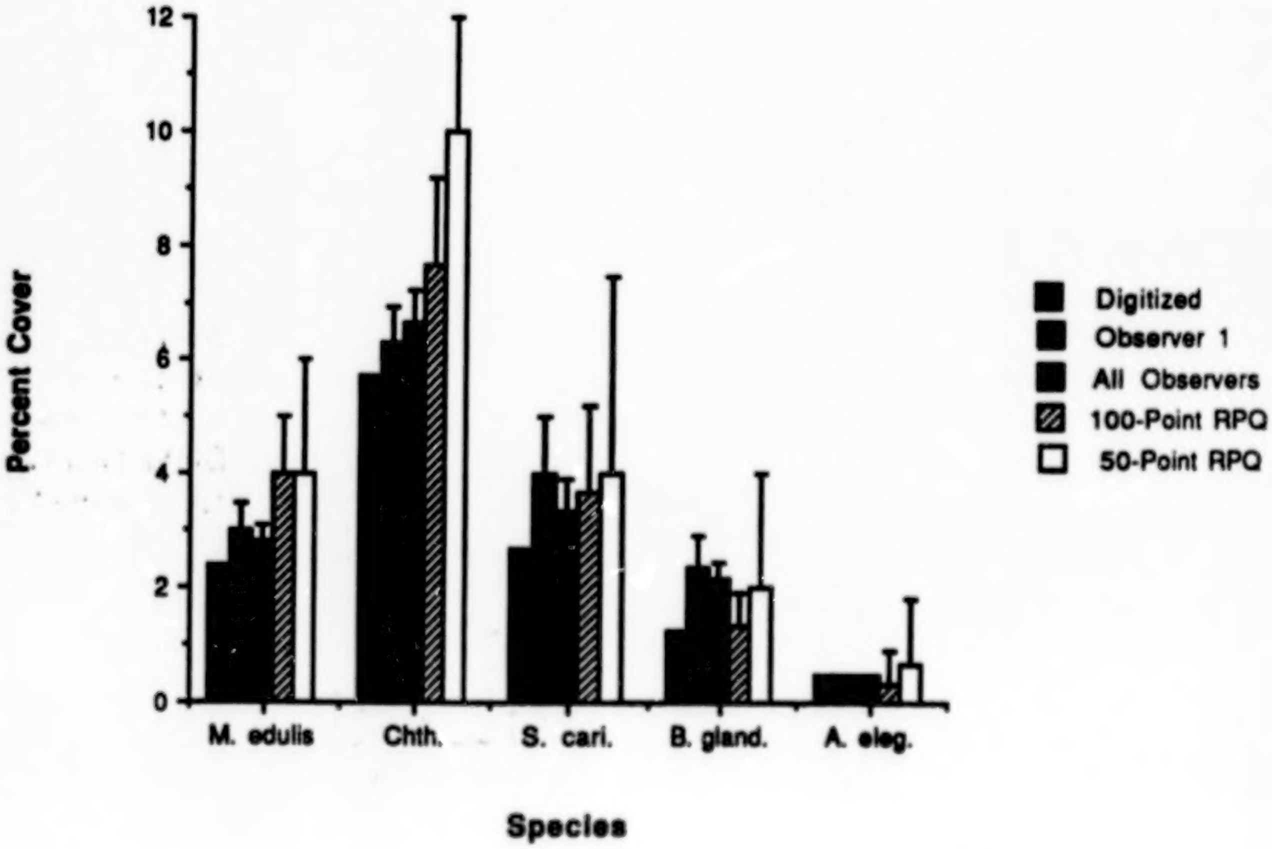


Figure 9: Quadrat 4 Algae

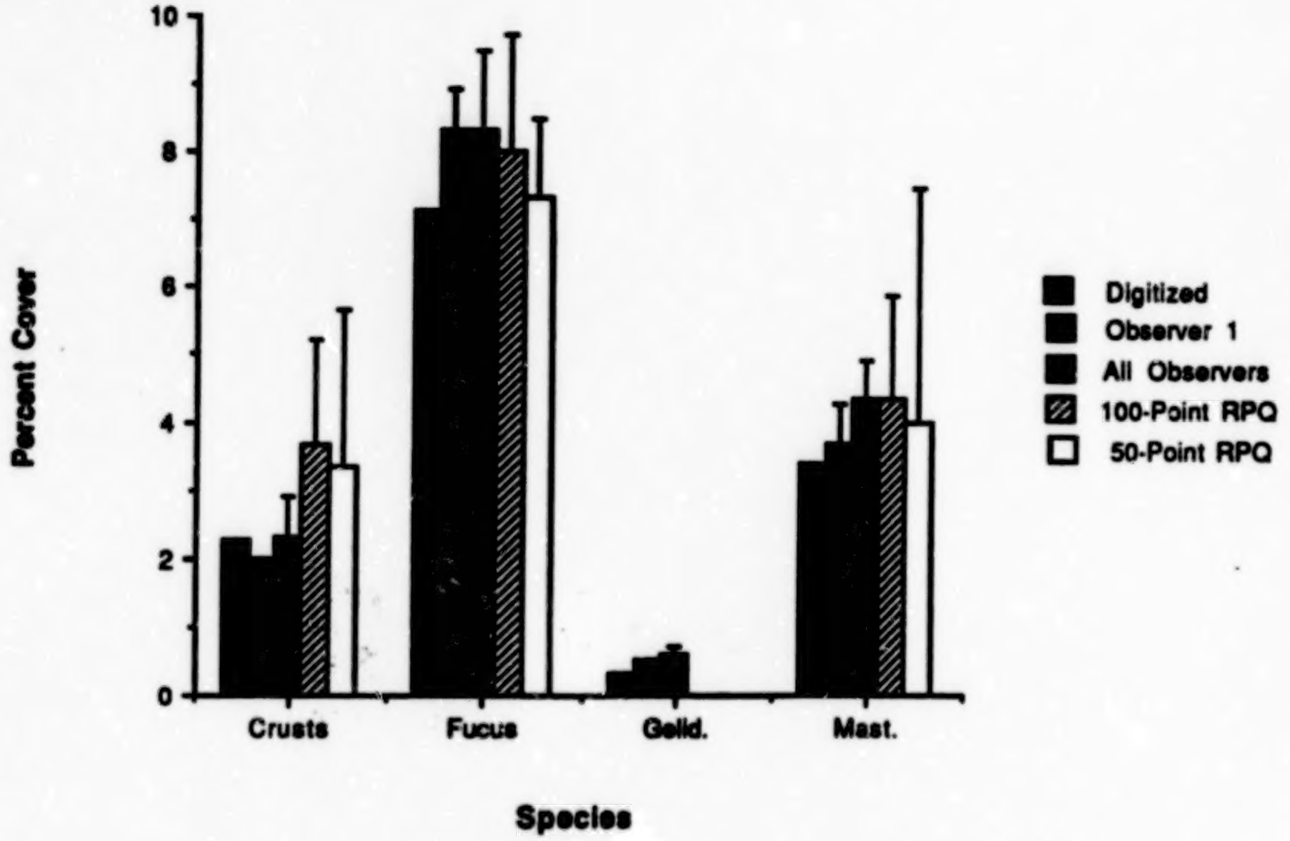


Figure 10: Quadrat 4 Animals

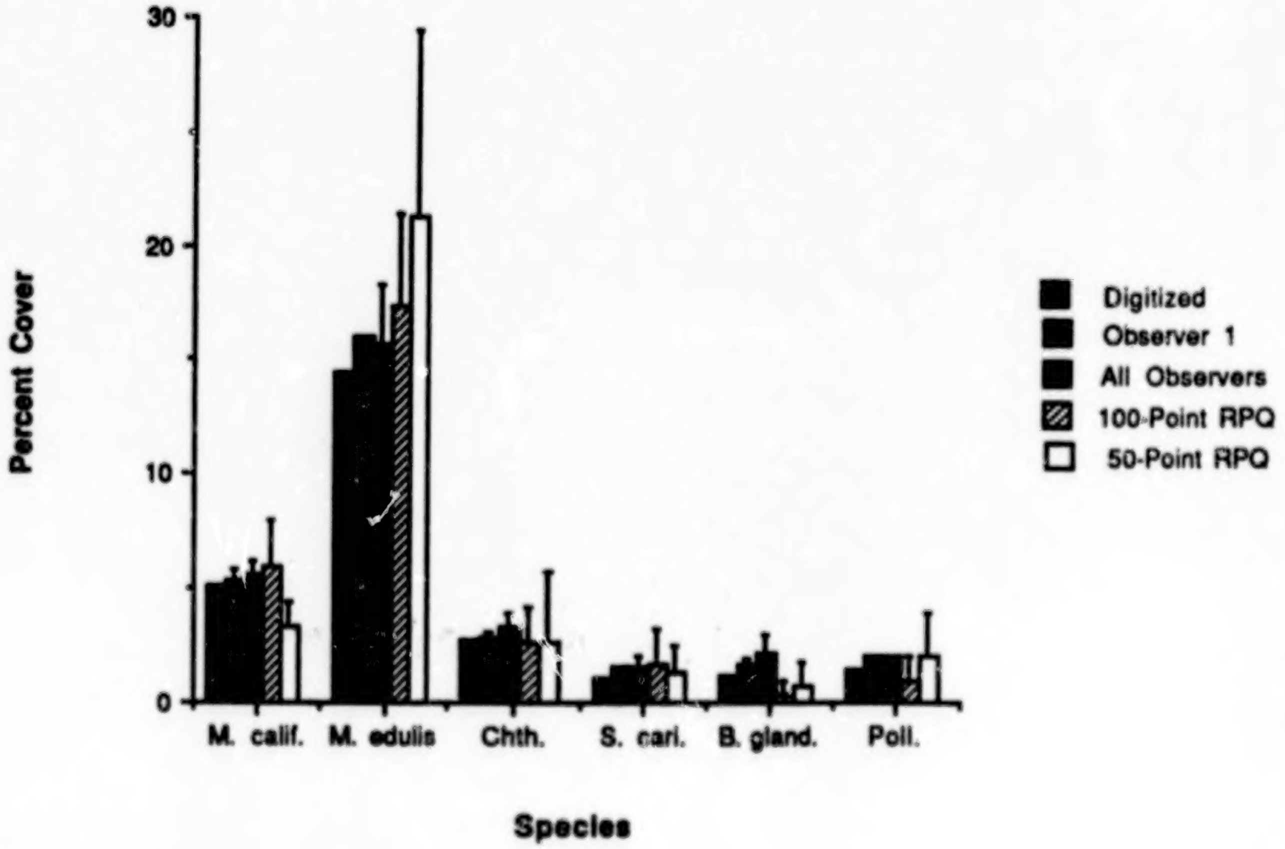


Figure 11: Quadrat 5 Algae

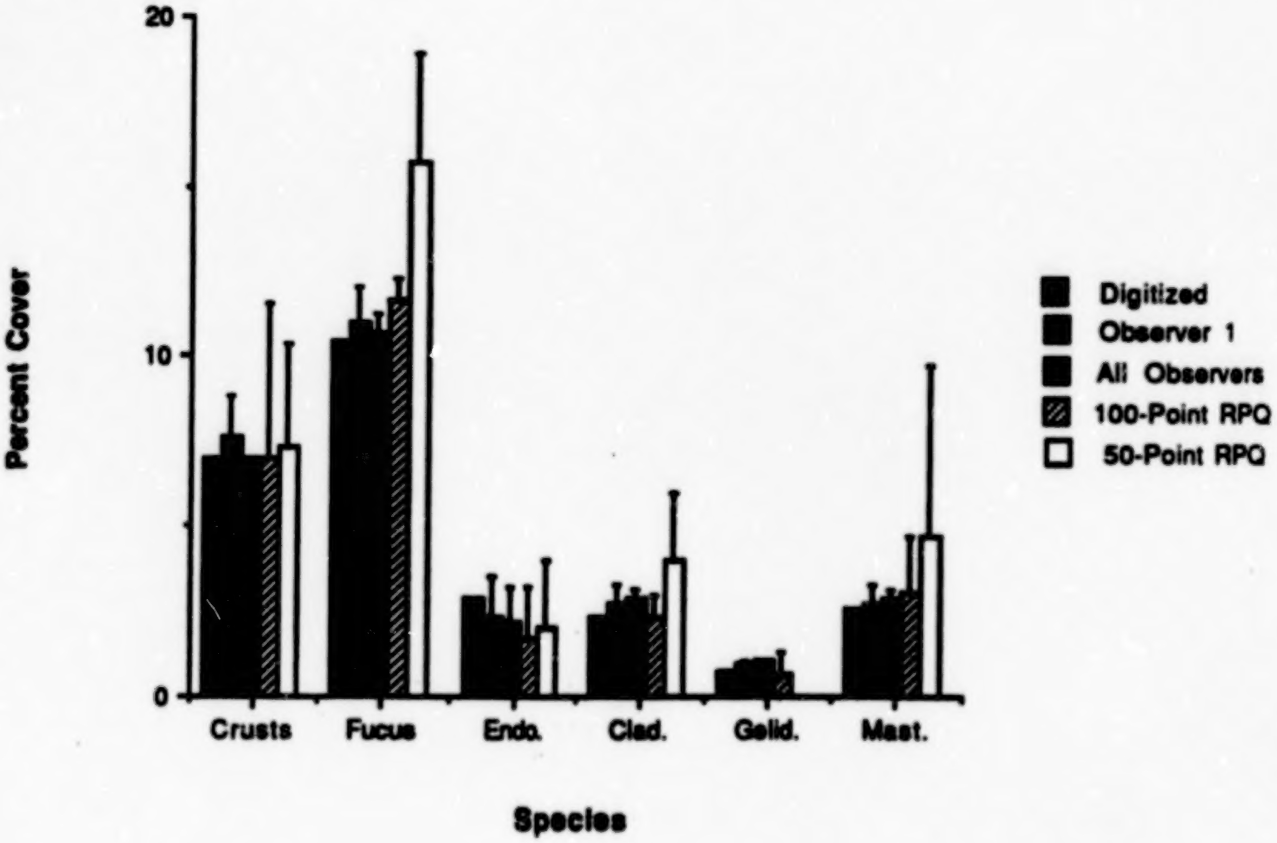


Figure 12: Quadrat 5 Animals

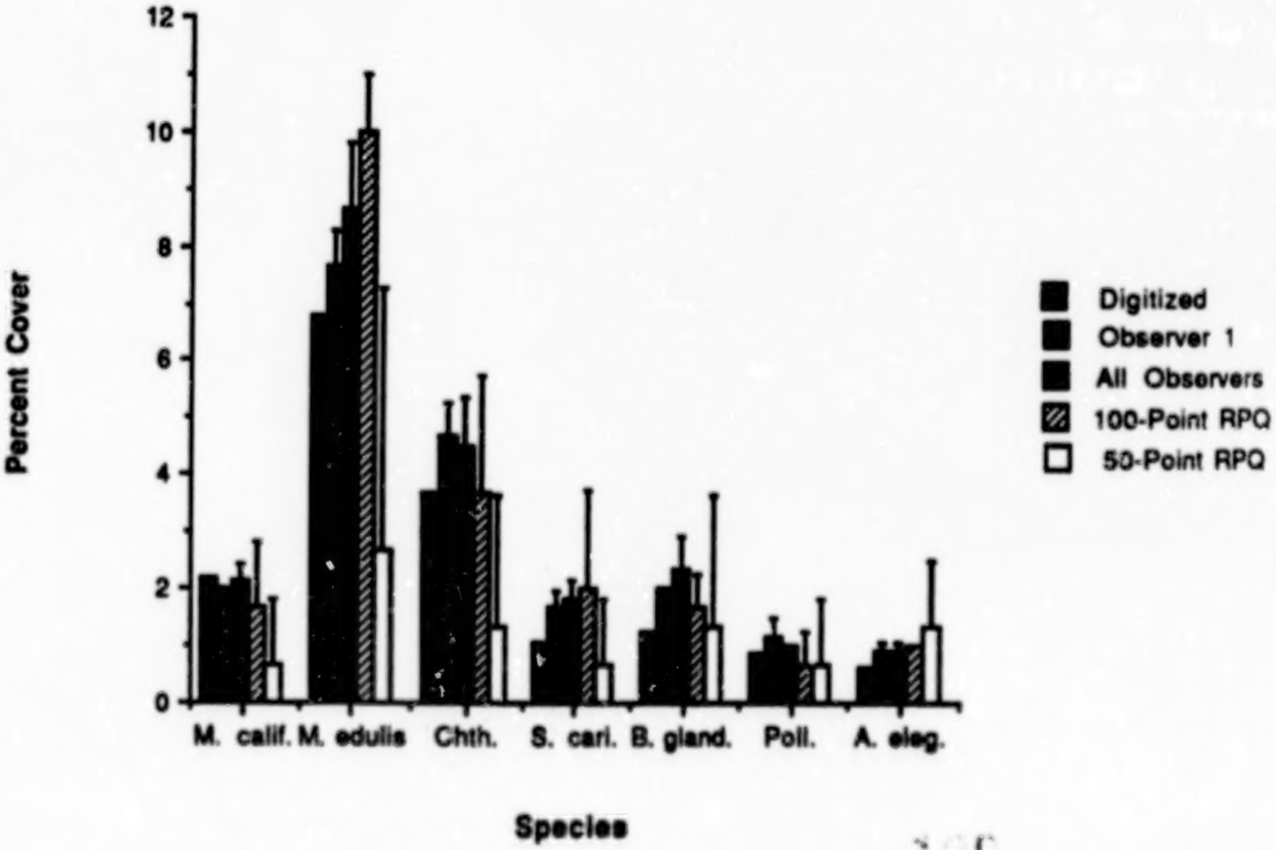


Figure 13: Quadrat 6 Algae

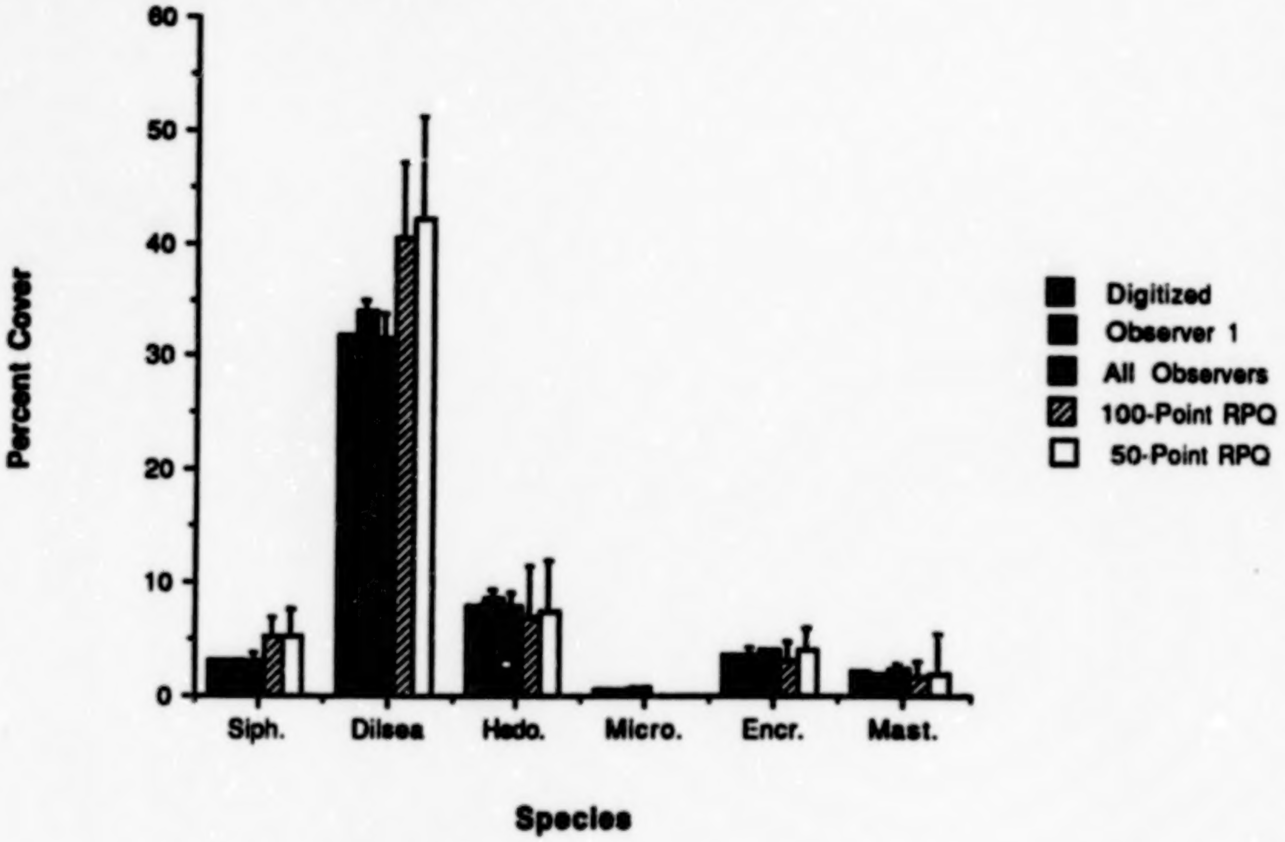


Figure 14: Quadrat 6 Animals

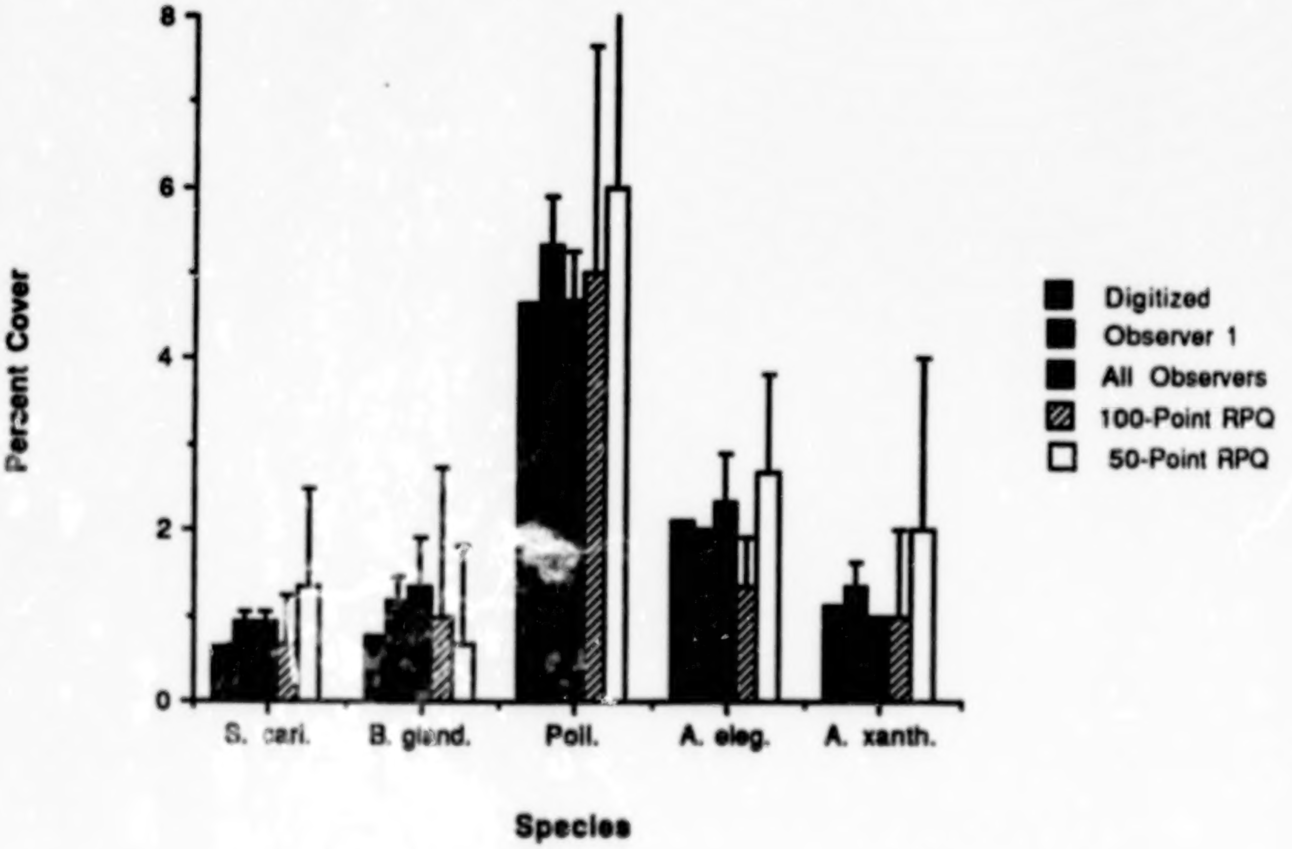


Figure 15: Quadrat 7 Algae

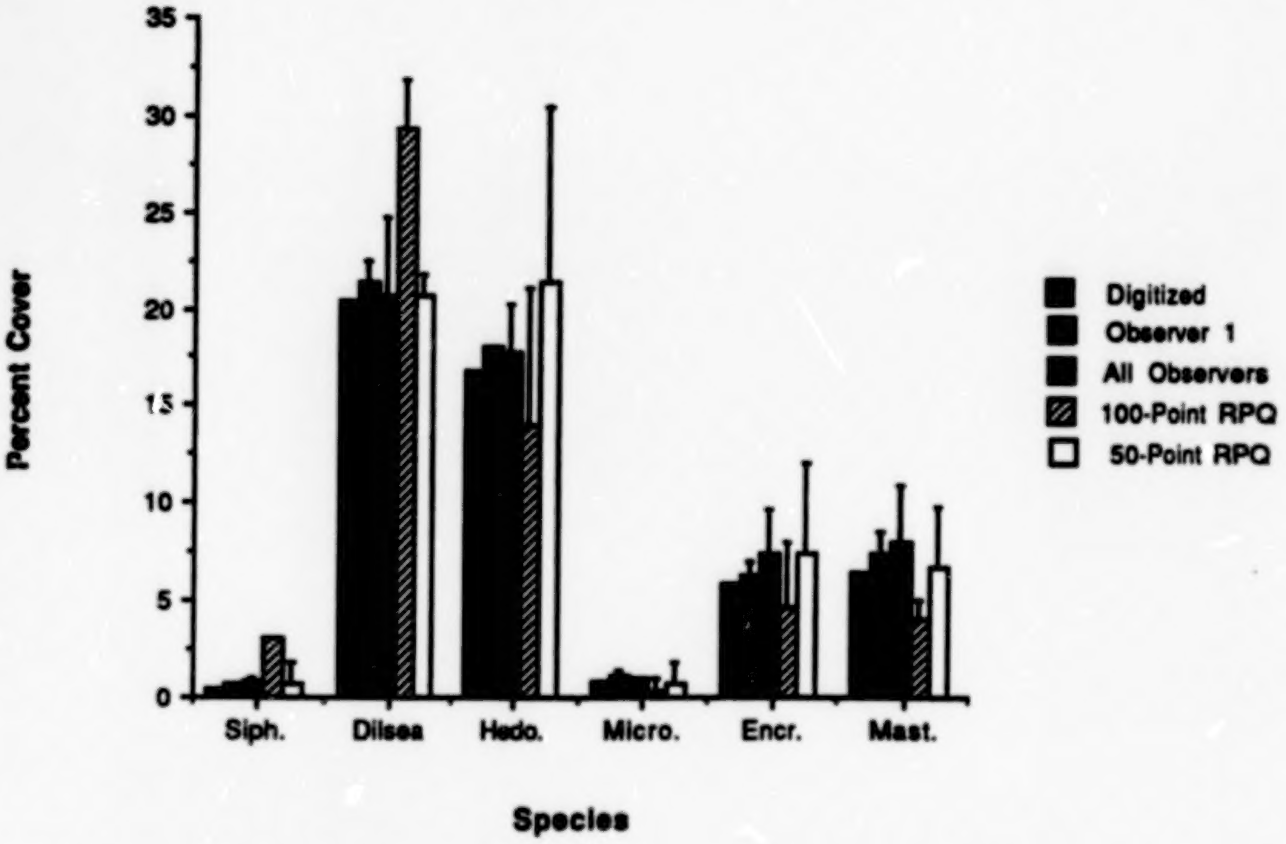


Figure 16: Quadrat 7 Animals

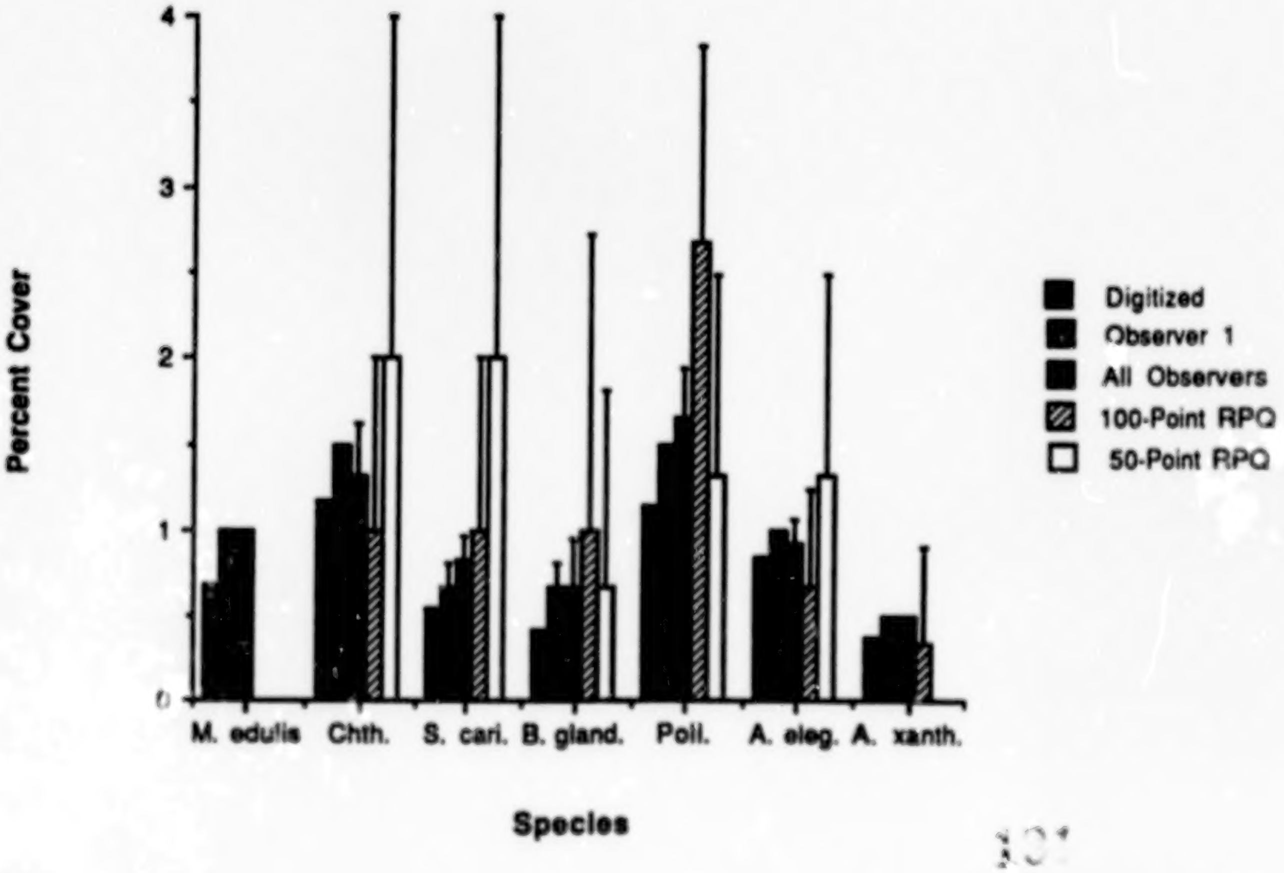


Figure 17: Quadrat 8 Algae

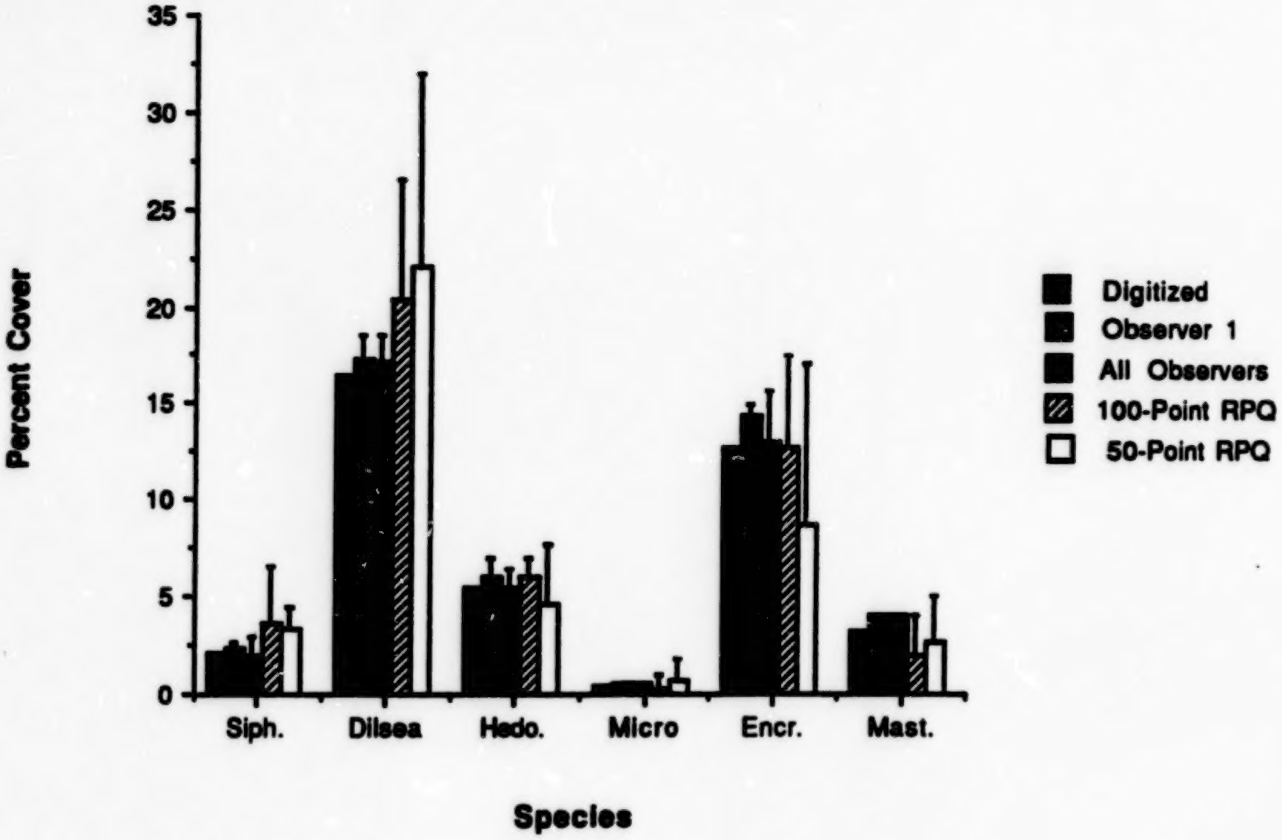


Figure 18: Quadrat 8 Animals

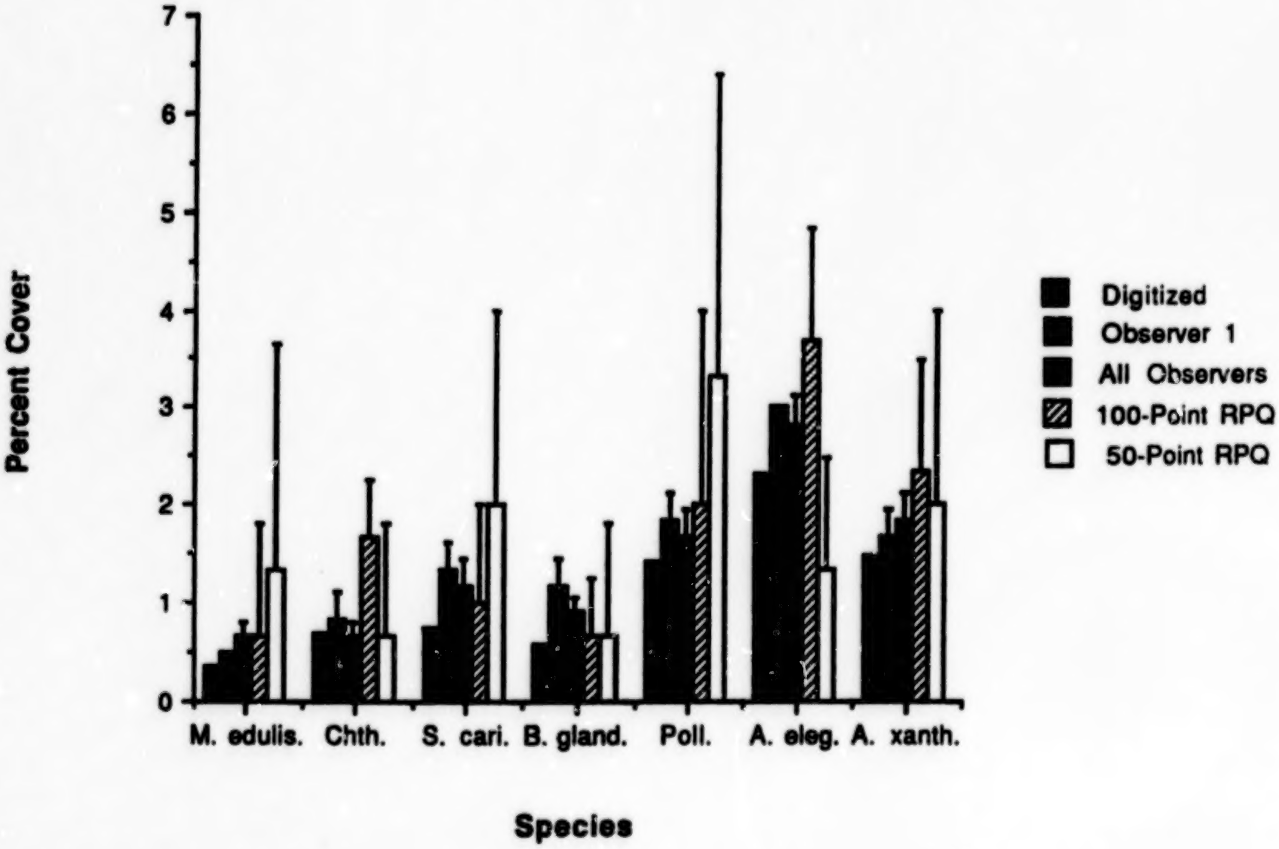


Figure 19: Quadrat 9 Algae

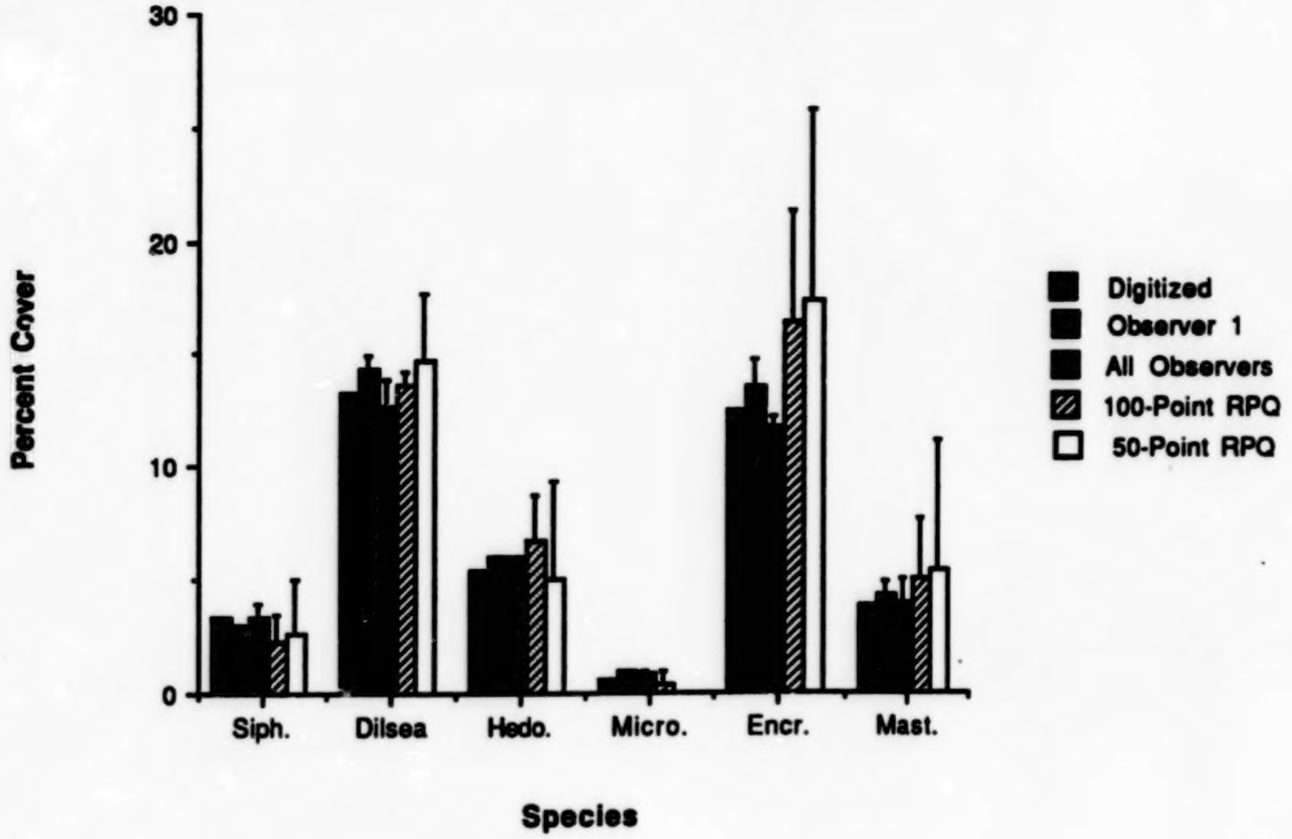


Figure 20: Quadrat 9 Animals

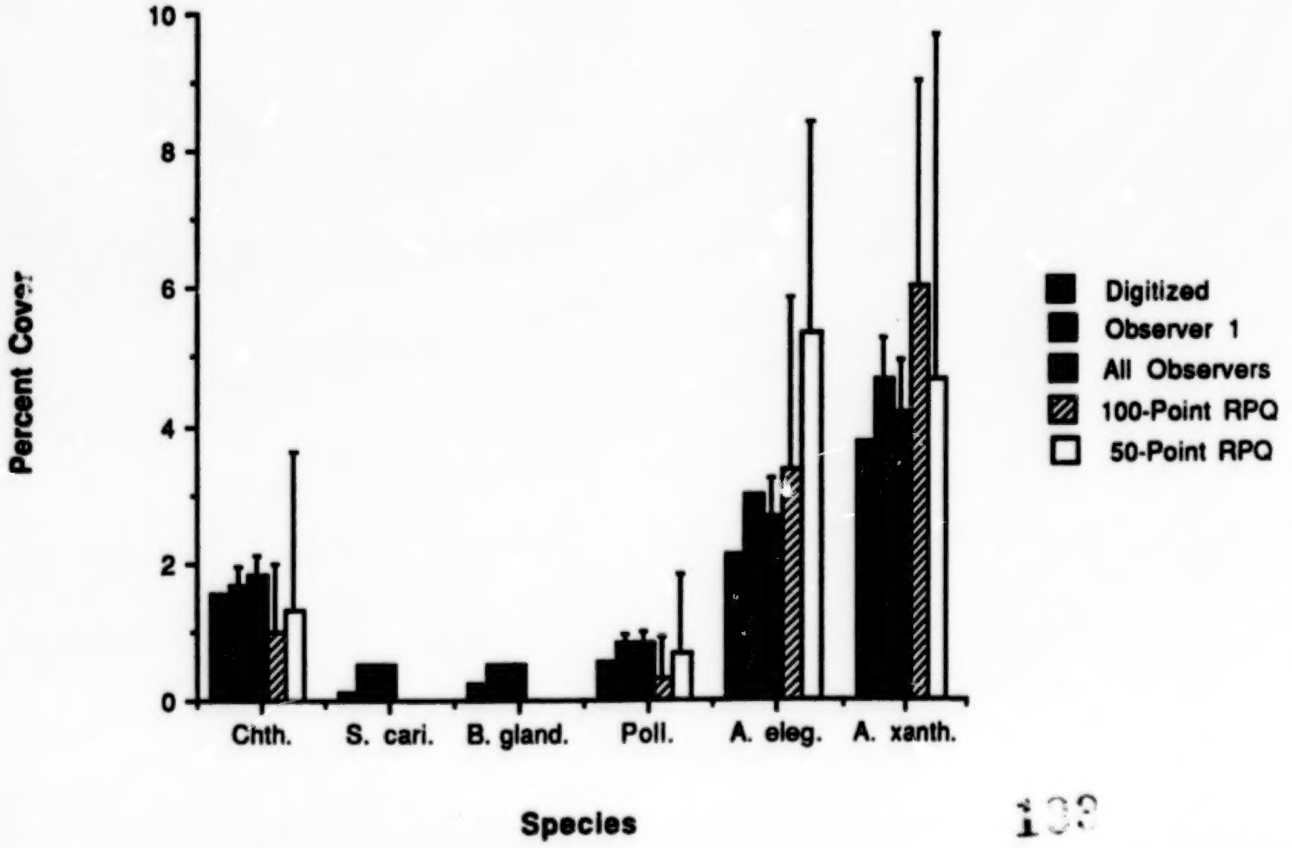


Figure 21: Quadrat 10 Algae

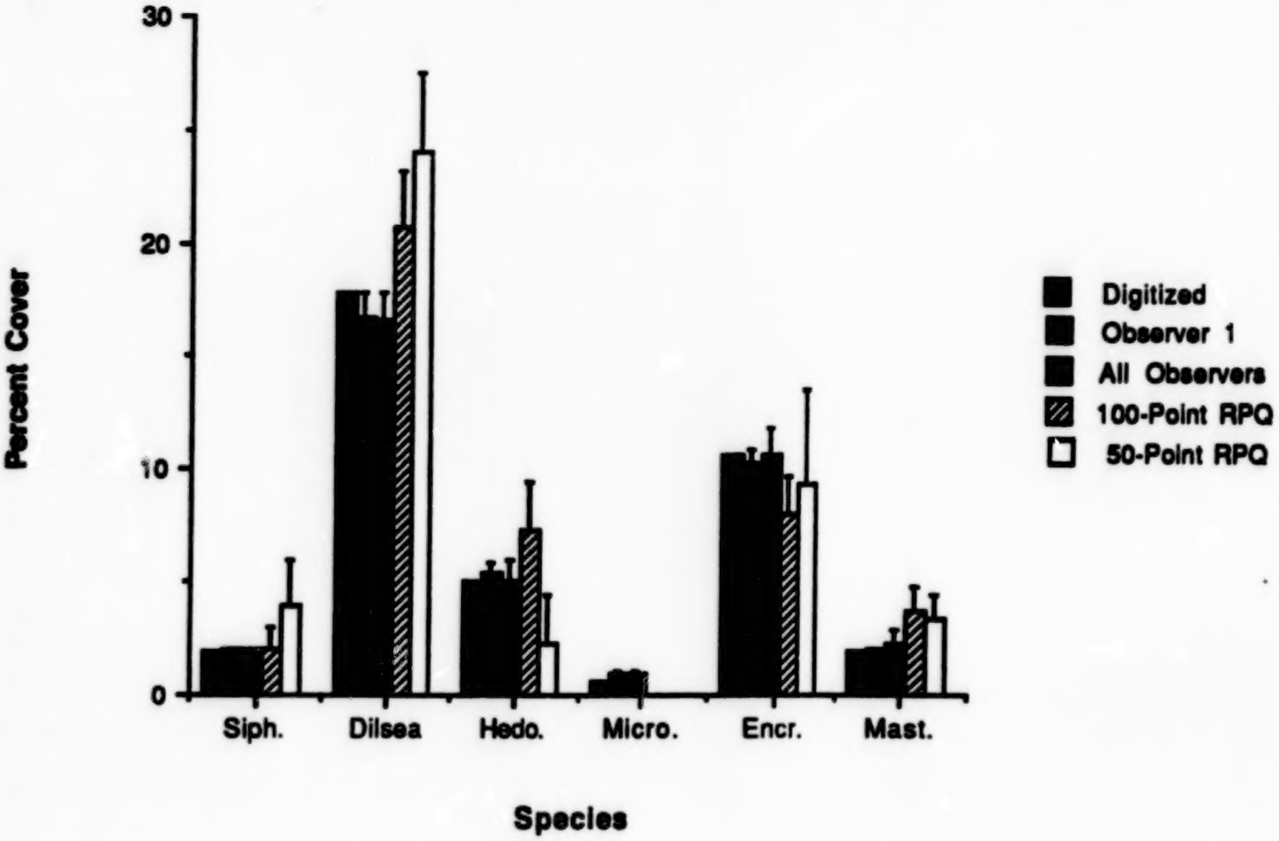
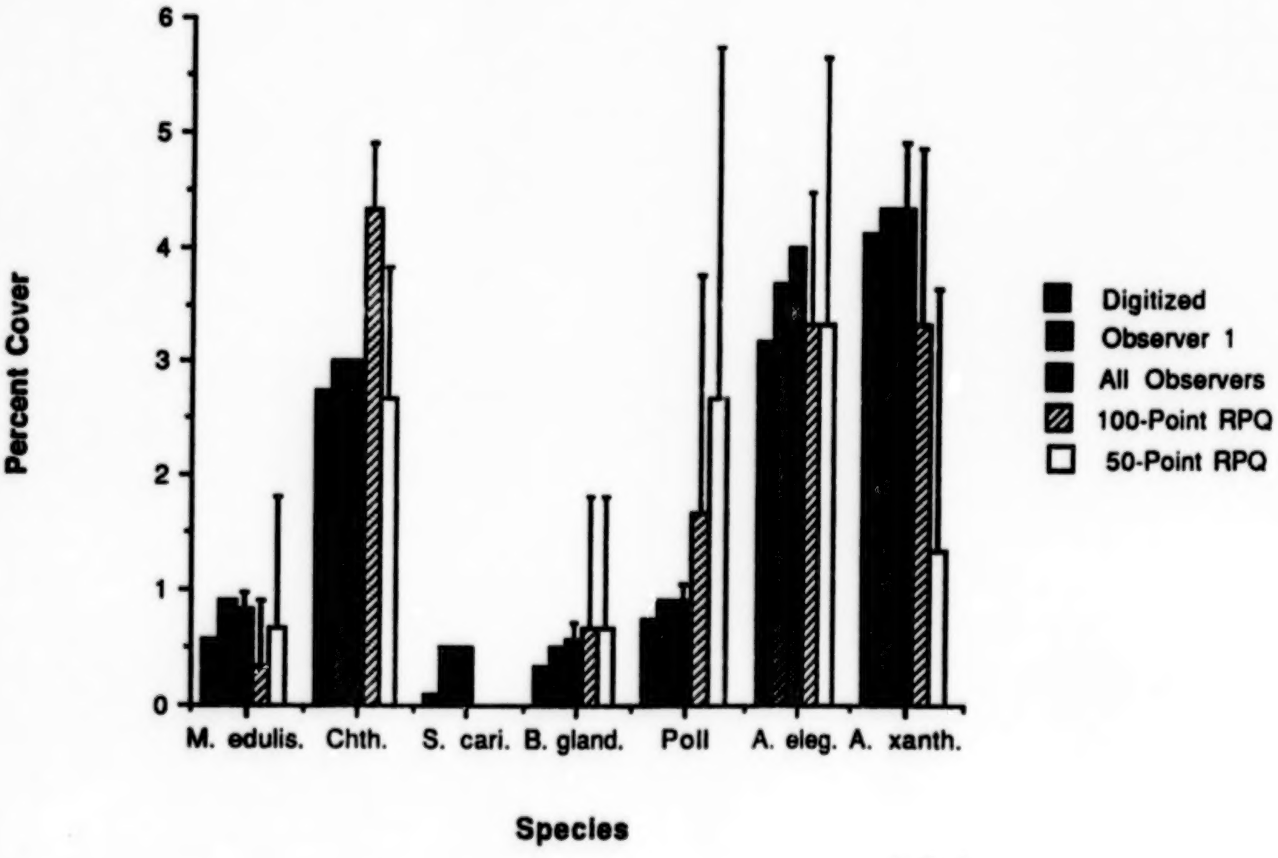


Figure 22: Quadrat 10 Animals



Figs. A-21, A-22

APPENDIX B. SPECIES FOUND IN OR ADJACENT TO ROCK TRANSECTS. See Table 1 for site code names. 1= rare, 2= common, 3=abundant (at the appropriate tidal levels).

	2BR	OSJ	CBR	CPP	CPE	TPP	TPE	BPR	SFR
LICHENS									
Verrucaria spp.	1		2	2	2		1		
Arthopyrenia spp.		1	2	3	1		1		
CYANOBACTERIA									
bluegreen film			1						
VASCULAR PLANTS									
Phyllospadix scouleri			2	1	1	1	2		
Phyllospadix torreyi			1						
ALGAE									
CHLOROPHYTA									
Order Acrosiphoniales									
Acrosiphonia spp.			1	1		1	1		
Order Cladophorales									
Cladophora spp.	1	1	1	2	1	3	1		
Order Codiales									
Codium fragile			1						
Bryopsis corticulans			1						
Bryopsis plumosa					1				
Derbesia marina					1				
Order Ulvales									
Ulva spp.	1		1	2	1	2	1	1	
Enteromorpha spp.		1							
PHAEOPHYTA									
Order Laminariales									
Laminaria sinclairii	2		2		1			1	3
Laminaria setchellii					1		1		
Alaria marginata	3		2		1	1	3		
Egregia menziesii			2	3	1	1	1		
Hedophyllum sessile	3				3		3		
Lessoniopsis littoralis	1				1		1		
Macrocystis integrifolia			2						
Order Fucales									
Fucus gardneri	2		3	3	2	3	2	1	1
Fucus spiralis			2						
Pelvetiopsis limitata					2	1			
Order Ectocarpales									
Ralfsia pacifica	1	2	2	3	2	3	3	1	1
Ralfsia fungiformis	1						1		
Ralfsia californica				1					
Cylindrocarpus rugosus				1	1				1
Leathesia difformis	1		1	1		1	1		
Analipus japonicus			1	2	1	1	1	1	1
Scytosiphon lomentaria				1	1	1			
Haplogloia andersonii		1							
Petalonia fascia						1			

	2BR	OSJ	CBR	CPP	CPE	TPP	TPE	BPR	SFR
Phaeostrophion irregulare			1	3		3	1	1	1
Myelophycus intestinalis			1						
Colpomenia spp. (2)			1						
Order Sphacelariales									
Sphacelaria racemosa				3		3			
Sphacelaria norrisii				1					
RHODOPHYTA									
Order Bangiales									
Porphyra spp.	1	1	1		1	1	1	1	1
Order Nemaliales									
Cumagloia andersonii	1					1	1		1
Order Palmariales									
Halosaccion glandiforme			3	1	1	1	1		
Palmaria mollis	1								
Order Hildenbrandiales									
Hildenbrandia spp.	2	2	3	3	3	2	2	2	2
Order Gelidiales									
Gelidium coulteri			1						
Order Corallinales									
Bossiella orbigniana subsp. dichotoma					1		1		
Bossiella plumosa	1		1	1	2	2	2	1	1
Bossiella chiloensis					1				
Chiharaea bodegensis			1						
Corallina vancouveriensis	2		2	1	3	1	2	1	1
Corallina officinalis			2		1				
Lithophyllum impressum	2				1		1	1	
Lithothamnion phymatodeum			2	1	1		1	1	
Pseudolithophyllum whidbeyense	2		1	1	2	2	2	2	2
Pseudolithophyllum neofarlowii			3			1	1		
Titanoderma sp.									
Order Gigartinales									
Constantinea simplex					1		1		
Cryptosiphonia woodii			1	1		1	1	2	
Dilsea californica	2	2	2	2	3	3	1	3	3
Farlowia mollis	1							1	
Endocladia muricata	1		2	3	2	3	2	2	1
Gigartina exasperata/ corymbifera				1					
Iridaea splendens	3	3	3	2	2	2	3	3	3
Iridaea cornucopiae	3				3			2	2
Gloiosiphonia capillaris			1						
Grateloupia doryphora		1							
Halymenia schizymenioides	1	1	1		2		1	1	
Prionitis spp.	1		2		1			1	2
Prionitis filiformis		2							

	BBR	OSJ	CBR	CPP	CPE	TPP	TPE	BPR	SFR
Erythrophyllum delesserioides	1						1		
Mastocarpus jardinii			2				1		1
Mastocarpus papillatus	2	1	2	3	1	3	3	2	1
"Petrocelis"	2	1	2	2	1	2	2	1	1
Peyssonnelia pacifica	2		2		2		1	1	2
Ahnfeltia plicata			1				1		1
Gymnogongrus spp.			1			1		1	
Plocamium cartilagineum					1		1		
Plocamium violaceum	1	1	1	1	2		1		
Plocamium oregonum					1				
Order Rhodymeniales									
Gastroclonium subarticulatum			2						
Order Ceramiales									
Callithamnion pikeanum	2				2		1	1	1
Ceramium pacificum			1		1				
Ceramium rubrum							1		
Microcladia borealis	2	1			3		1	1	1
Neoptilota asplenioides	2	1	1	1	1	1	1		
Neoptilota hypnoides					1				
Cryptopleura spp.	1		1		3		1		
Delesseria decipiens							1		
Laurencia spectabilis			1		1		2		
Neorhodomela larix	1		1	2	1	2	1		
Odonthalia floccosa			2	2	3	1	2		
Odonthalia washingtoniensis					1		1		
Polysiphonia hendryi				2	3	2	2	2	3
Polysiphonia pacifica							1		
Polysiphonia urceolata				2					
Pterosiphonia dendroidea		2		2					
Pterosiphonia bipinnata	2	2	3					1	3
Membranoptera sp.	1								

ANIMALS

	BBR	OSJ	CBR	CPP	CPE	TPP	TPE	BPR	SFR
PH. SARCOMASTIGOPHORA									
Gromia oviformis				1					
PH. PORIFERA (SPONGES)									
Leucosolenia sp.			1						
Halichondria panicea	2		1		2		1		1
Ophlitaspongia pennata							1		
Haliclona spp.	1	1					1		
white sponge	1	1			1		1		
yellow sponge	1	1						1	

	2BR	OSJ	CBR	CPP	CPE	TPP	TPE	BPR	SFR
PH. CNIDARIA (hydroids, anemones)									
erect hydroids	2	1					1	2	1
Anthopleura elegantissima	2	1		1	1	1	3	3	2
Anthopleura xanthogrammica	3	1		1	1	1	2	2	3
Anthopleura artemisia						1		1	
Urticina spp.			1			1			
Epiactis prolifera			1			1	1		
PH. PLATYHELMINTHES (FLATWORMS)									
Polyclads					1			1	
PH. NEMERTEA (RIBBONWORMS)									
Paranemertes peregrina	1				1		1	2	
Emplectonema gracile	1				2		1	3	2
Amphiporus imparispinosus	1	1			2		2	2	
PH. ANNELIDA (POLYCHAETE WORMS)									
Serpulids	1		1		1		1		
Sabellids									
Potamilla neglecta + *P. occelata*	2				1	3	2	1	2
Other Sabellids	1			1					
Nereids (unidentified)	1	1			1		1	2	1
Pista elongata					1		1		
Eudistylia vancouveri	1	1						2	3
Syllis stewartii							2		
Nephtyds									
Nephtys ferruginea		1							
PH. SIPUNCULA (ACORN WORMS)									
Phascolosoma agassizii					1				
PH. MOLLUSCA: CHITONS									
Lepidochitona dentiens	1		1		3	2	3	1	
Tonicella lineata	2		1		3		2	2	1
Mopalia ciliata + *lignosa* + *hindsii*	1	2	1				1	3	2
Mopalia muscosa			1						
Katharina tunicata	2				3		2	1	
Cryptochiton stelleri							1		
Dendrochiton flectens						1	1		
GASTROPODS									
Tricolia pulloides									
Tegula funebralis			2	2		1			
Lirularia succincta			2						
Diodora aspera							1		
Acmaea mitra							1		
Lottia pelta	3		2	2	3	2	3	2	2
Lottia digitalis	3	3	2	3	3	2	3	3	3
Lottia strigatella	3	3	3	3	3	3	3	3	3

	2BR	OSJ	CBR	CPP	CPE	TPP	TPE	BPR	SFR
Lottia painei							1		
Tectura scutum		1	2						
Tectura persona			1						
Lacuna spp.	2		3	3	2	3	3	2	2
Littorina scutulata	3	3	3	3	3	3	3	3	3
Littorina sitkana	2				2				
Littorina tatooshensis	2				2				
Nassarius fossatus									1
Margarites spp.				1					
Bittium eschrichtii			1						
Crepidula perforans			1						
Ceratostoma foliatum					1		1		
Ocenebra lurida			1		1		1		
Nucella lamellosa				1					
Nucella canaliculata	2				1	1	1	1	
Nucella emarginata	3	3		2	2	2	3	3	3
Searlesia dira				1					
Alia carinata			1						
Alia gausapata	1		3	2		2	2		
Amphissa columbiana					1				
Archidoris montereyensis	1				1		1		
Cadlina luteomarginata								1	
Hermissenda crassicornis			1			1		1	
Onchidella borealis	1		1		2				
Siphonaria thersites					2				
Triopha sp.						1			
Dendronotus frondosus								1	

BIVALVES

	2BR	OSJ	CBR	CPP	CPE	TPP	TPE	BPR	SFR
Mytilus californianus	3	1			3		3		2
Mytilus edulis	3	3			3	2	3	3	3
Petricola carditoides								1	
Semele rubropicta						1			
Hiatella arctica	1				1				
Boring clams	2			1	2			2	2

PH. ARTHROPODA: ISOPODS

	2BR	OSJ	CBR	CPP	CPE	TPP	TPE	BPR	SFR
Idotea spp. (*wosnesenskii* + *ochotensis* + *schmitti* + *montereyensis*)	2	1	1	3	2	2	2	2	3
Synidotea ritteri + *pettiboneae*								1	2
Ligia spp.	3	1	1				2		
Gnorimosphaeroma oregonense		1					3		2
Dynamenella benedictii			1						

	2BR	OSJ	CBR	CPP	CPE	TPP	TPE	BPR	SFR
AMPHIPODS									
Gammarid Species, incl. *Hyale frequens* + *anceps* + *pugettensis*	3	1	1	2	1	2	3	1	3
Jassa spp.		2							
Parallorchestes sp.								1	
Corophium brevis								1	
DECAPODS									
Hemigrapsus nudus						1	1		
Oedignathus inermis	1				2			2	1
Pagurus spp.	1		2	2	1	3	1	1	2
Petrolisthes spp.	1								
"spider crabs" (majids)	1			1	1			1	
Cancer oregonensis	1			2					
Pugettia producta		1							
Shrimp (unident.)	1			1	1				
BARNACLES									
Semibalanus cariosus	3	3			2		2	2	2
Balanus glandula	3	3	2	2	3	3	3	3	3
Balanus nubilus	1						1		
Chthamalus dalli	2	2	3	3	2	3	3	3	2
Pollicipes polymerus	3	3			3		3	2	3
Pycnogonids including *Achelia alaskensis*			1	1					2
PH. BRYOZOA									
Heteropora magna							1		
Bugula spp.			1						
encrusting spp.	1	1	1				1	1	
Flustrellida sp.	2								
Alcyonidium polyoum									1
Membranipora membranacea			1						
Tricellaria spp.							1		
PH. ECHINODERMATA: URCHINS									
Strongylocentrotus droebachiensis			1				1		
Strongylocentrotus purpuratus					3		1		
SEA CUCUMBERS									
Cucumaria miniata							1		
Eupentacta quinquesemita			1				1		
SEASTARS									
Pisaster ochraceus	3	1		1	2	1	3	1	3
Leptasterias hexactis	3	1	1		2	2	3	3	3
Pynopodia helianthoides						1	1		
Henricia leviuscula			1			1	1		

	2BR	OSJ	CBR	CPP	CPE	TPP	TPE	BPR	SFR	
PH. UROCHORDATA: TUNICATES										
Styela montereyensis	1	1							1	2
Perophora annectens			1							
Clavelina huntsmani			1							
Aplidium spp.			1							
Didemnum sp.			1				1			
Pyura sp.									1	
VERTEBRATES: FISHES										
Gobies (clingfish)							1			
Blennies				1			1			
Cottids (sculpins)	2			2						

APPENDIX C. SPECIES FOUND IN OR ADJACENT TO COBBLE TRANSECTS.

Symbols as in Appendix II.

	SANDPT	NORWEG	ALAVA	KAYOST	CHILEAN
LICHENS					
Verrucaria spp.	2	1			
CYANOBACTERIA					
bluegreen crusts			3		
VASCULAR PLANTS					
Phyllospadix scouleri	3	3	3	3	2
Phyllospadix torreyi		1	1	2	
Phyllospadix serrulatus		2	2		
ALGAE					
CHLOROPHYTA					
Order Acrosiphoniales					
Acrosiphonia spp.	1		1		
Order Cladophorales					
Cladophora spp.		1	1	1	1
Order Codiales					
Derbesia marina	1	1			
Bryopsis corticulans			1		
Codium fragile			1		
Order Ulvales					
Ulva spp.	2	1	3	2	1
Enteromorpha spp.	2		1		
PHAEOPHYTA					
Order Laminariales					
Costaria costata	1				
Laminaria setchellii	1				
Laminaria sinclairii			1		
Alaria marginata	3				1
Egregia menziesii	2	1			3
Hedophyllum sessile	1				
Macrocystis integrifolia	2		1		
Nereocystis luetkeana	1				
Order Fucales					
Fucus gardneri	2	3	3	3	1
Fucus spiralis	2	2	1		
Pelvetiopsis limitata		1			
Cystoseira geminata			3	1	
Sargassum muticum			1		
Order Ectocarpales					
Ralfsia pacifica	2	2	2	2	2
Ralfsia fungiformis	2	2			1
Ralfsia californica	2	1		1	2
Leathesia difformis	1		1	1	
Analipus japonicus		1			
Colpomenia peregrina			1		1
Colpomenia bullosa			1		

	SANDPT	NORWEG	ALAVA	KAYOST	CHILEAN
Scytosiphon lomentaria			1		1
Phaeostrophion irregulare				2	1
Myelophycus intestinalis			1	1	
Soranthera ulvoidea			1	1	1
Order Sphacelariales					
Sphacelaria spp.				2	
Order Desmarestiales					
Desmarestia ligulata		1			
RHODOPHYTA					
Order Compsopogonales					
Smithora naiadum	1	1			
Order Bangiales					
Porphyra spp.	1	1		1	
Order Acrochaetiales					
Audouinella spp.		1			1
Order Nemaliales					
Scinaia confusa		1			
Order Palmariales					
Halosaccion glandiforme	1	1		1	
Rhodophysema elegans		2		1	
Order Hildenbrandiales					
Hildenbrandia spp.	3	3	2	2	3
Order Gelidiales					
Gelidium coulteri		3	1		
Order Corallinales					
Bossiella orbigniana subsp. *dichotoma*	1	1	1		
Bossiella cretacea	1	1			
Bossiella plumosa	1	1		1	1
Calliarthron tuberculosum	1	1			
Chiharaea bodegensis	1				
Corallina vancouveriensis	2	1	1	1	1
Corallina officinalis	1	2	1	1	
Corallina frondescens	1				
Lithothrix aspergillum	1		1		
Lithophyllum impressum	1				
Lithothamnion phymatodeum	2	2	1		1
Pseudolithophyllum whidbeyense	2	3	2	2	2
Pseudolithophyllum neofarlowii	1	2	1		1
Serraticardia macmillanii		1			
Titanoderma sp.		1	1		
Order Gigartinales					
Constantinea simplex	1	1			
Cryptosiphonia woodii		1		2	
Dilsea californica	1	2		2	1
Farlowia mollis		1			
Endocladia muricata	2	2			
Gigartina exasperata/ corymbifera	1	1	1	1	

	SANDPT	NORWEG	ALAVA	KAYOST	CHILEAN
Iridaea splendens	2	3		2	2
Iridaea heterocarpa		1			
Iridaea cornucopiae		1			
Rhodoglossum affine		2	1		
Grateloupia setchellii				1	
Grateloupia doryphora		3	1		
Halymenia schizymenioides	1	1			
Callophyllis spp.	1				
Prionitis spp.	3	2	1	1	
Schizymenia pacifica		1			1
Mastocarpus jardinii	1	2			
Mastocarpus papillatus	2	3	1	2	3
"Petrocelis"	2	1	1		1
Peyssonnelia pacifica	1	1	1		
Ahnfeltia fastigiata			1	1	1
Gymnogongrus leptophyllus			1		
Gymnogongrus chiton			1		
Order Rhodymeniales					
Gastroclonium subarticulatum	2	3	3		
Order Ceramiales					
Callithamnion pikeanum		1			
Ceramium pacificum		1	1		
Ceramium washingtoniense		3	1		
Microcladia borealis		1		1	1
Microcladia coulteri		1			
Neoptilota asplenioides	1	1		1	
Cryptopleura lobulifera		2			1
Cryptopleura ruprechtiana	1		1		1
Polyneura spp.	2	1			1
Laurencia spectabilis	2	3	1	1	
Neorhodomela larix	2	2	2	2	2
Odonthalia floccosa	3	3	2	2	2
Odonthalia washingtoniensis	1	1			
Polysiphonia spp. (*hendryi* + *pacifica* + *urceolata* + *paniculata* + *eastwoodae*)			1	1	1
Pterosiphonia spp. (*bipinnata* + *dendroidea*)		2	1		

	SANDPT	NORWEG	ALAVA	KAYOST	CHILEAN
ANIMALS					
PH. SARCOMASTIGOPHORA					
Gromia oviformis		3			
PH. PORIFERA (SPONGES)					
Halichondria panicea			1		
Ophlitaspongia pennata	1	1	1		
Haliclona spp.	1	1	1		
other sponges (unident.)	2	2	1		1
PH. CNIDARIA (hydroids, stauromedusans, anemones)					
erect hydroids		1			
Anthopleura elegantissima	1	1	1	1	
Anthopleura xanthogrammica	1	1	1		
Anthopleura artemisia					
Urticina spp.	1	2	2	1	
Epiactis prolifera	1	2	1		
Alcyonium sp.	1				
PH. NEMERTEA (RIBBONWORMS)					
Tubulanus polymorphus			1		
Paranemertes peregrina	1	1	1		
Emplectonema gracile	1				
Amphiporus spp.	1	1	1		1
unident. nemerteans		2			
PH. ANNELIDA (POLYCHAETE WORMS)					
Serpulidae (incl. Serpula vermicularis + Protula pacifica)	1	2			1
Spirorbidae*	3	3	3	3	3
Sabellidae (incl. Indanthyrsus armatus, Oriopsis spp. + unident.)					2
Spionidae					
Spio filicornis			1		
Pygospio elegans			3		
Polydora proboscidea	2	2	3		
Maldanidae: Euclymene zonalis		2	3		
Terebellidae					
Thelepus crispus			2		1
Nicolea zostericola		1			
Pista elongata + brevibranchiata	1	1	1		
Eupolymnia heterobranchia					1
Flabelligeridae					
Pherusa plumosa + inflata		1	1		
Nereidae					
Platynereis bicanaliculata		1			2
Nereis vexillosa	1	1	2		

	SANDPT	NORWEG	ALAVA	KAYOST	CHILEAN
Arabellidae: *Drilonereis longa*		1			
Capitellidae					
Decamastus gracilis		1			
Capitella capitata	1				
Oweniidae: *Owenia fusiformis*				2	
Orbiniidae					
Naineris dendritica	1	2		1	2
Naineris quadricuspida + *uncinata*		1	1	1	
Scoloplos sp.				1	1
Onuphidae: *Nothria conchylega*			1		
Arenicolidae					
Arenicola marina		1	3		
Abarenicola pacifica			1		
Lumbrineridae					
Lumbrineris luti + *latreilli* + *californiensis* + *zonata* + *japonica*		2	2	2	1
Cirratulidae					
(*Chaetozone acuta* + unident.)				2	1
Syllidae: *Syllis variegata*					3
Nephtyidae					
Nephtys californiensis			1		
N. caecoides			1		
Opheliidae					
Ophelina sp.	1				
Armandia brevis					1
Euzonus sp.	1				
Polynoidae					
Halosydna brevisetosa	1	1	1		1
Tenonia priops		1			
Sabellariidae					
Sabellaria cementarium	1	1			
Idanthyrsus armatus					1
PH. SIPUNCULA (ACORN WORMS)					
Phascolosoma agassizii	2	2	2	2	1
PH. MOLLUSCA: CHITONS					
Lepidozona willetti + *cooperi*		1	1		
Lepidochitona dentiens	2	3	1	1	3
Tonicella lineata	2	3			1
Mopalia ciliata + *lignosa*	1	2	1	1	1
Mopalia muscosa	1	1	2	1	1
Katharina tunicata	1				
Dendrochiton flectens					1
Leptochiton nexus		1			
Placiphorella velata		1			

	SANDPT	NORWEG	ALAVA	KAYOST	CHILEAN
GASTROPODS					
Tegula funebralis	3	3	2	2	3
Tegula brunnea			1		
Lirularia succincta	2	3	2	1	
Margarites pupillus	1		3	1	1
Diodora aspera	1		1		1
Acmaea mitra	1	1			
Lottia pelta	2	2	2		1
Lottia digitalis	1	1			
Lottia strigatella	2	3	2	2	2
Lottia painei	1				
Tectura scutum	3	2	2	1	3
Tectura fenestrata	1	1		2	3
Tectura persona	1	2			
Lacuna spp.	3	2	2	2	3
Amphissa versicolor	1				
Granulina margaritula			3		
Tricolia pulloides			3		
Opalia borealis		1			
Alvaria sp.		1			
Barleeia haliotiphila		1			
Littorina scutulata	3	3	2	2	2
Littorina sitkana		1	2		
Bittium eschrichtii	2		2	3	1
Crepidula adunca	1	1	2	1	1
Crepidula perforans			1		
Opalia borealis		1			
Calliostoma ligatum	1				
Ocenebra lurida	1	1	1		
Nucella lamellosa				1	1
Nucella canaliculata	1				
Nucella emarginata	1	1			1
Searlesia dira	3	2	2	1	
Alia carinata + *gausapata*	3	3	2	1	1
Dialula sandiegensis		1			
Rostanga pulchra	1	1	1		
Archidoris montereyensis	1	1			
Cadlina luteomarginata		1			
Hermissenda crassicornis	1				
Onchidella borealis	1				
Triopha sp.	1		1		
BIVALVES					
Mytilus californianus	1	1			
Mytilus edulis	1	1	1		1
Adula spp.		1			
Sphenia ovoidea		1			
Tellina nucleoides		1			
Macoma spp. (juv. + unid.)	1	1	1	1	1
Macoma inquinata		2	2	1	
Protothaca staminea	1	2	1	2	
Transennella tantilla		2	3		

	SANDPT	NORWEG	ALAVA	KAYOST	CHILEAN
Saxidomus giganteus	1		1	1	
Petricola carditoides		1			
Semele rubropicta				1	
Pododesmus cepio	1		1		
Mya arenaria		2	1		
Hiatella arctica	1		1		
Penitella spp.					1
Cryptomya californica			1		
PH. ARTHROPODA: ISOPODS					
Idotea wosnesenskii	3	1	1	1	1
Idotea ochotensis + *schmitti* + *urotoma* + *aculeata* + *kirchanskii* + *fewkesi*	2	2	2	2	1
Cirolana harfordi	2				
Exosphaeroma inornata + *rhomburum* + *crenulatum*	3	2		2	2
Gnorimosphaeroma noblei + *oregonense* + *insulare*				2	3
Dynamenella glabra		1	1		1
Littorophiloscia richardsonae		1			
Alloniscus perconvexus		1			
AMPHIPODS					
Paramoera columbiana					1
Pontogeneia cf. *ivanovi*				1	
Amphilochus litoralis					1
Corophium sp.	3				
Melita spp.		2			
Maera simile + *danae*	1	1			
Hyale plumulosa	2	1			
H. frequens				2	2
Parallorchestes sp.				1	1
Ampithoe lacertosa		1		2	
Atylus levidensus	1				
Megalorchestia pugettensis				3	
M. californiana + *columbiana*	2			3	
Traskorchestia traskiana		3			
T. georgiana	3		3		
Eohaustorius sawyeri				2	
Orchomene pinguis			1		
Cymadusa uncinata			1		
DECAPODS					
Hemigrapsus nudus	3	3	3	2	2
Hemigrapsus oregonensis	1	2	1		1
Cancer oregonensis	1	2			1
Cancer productus			1		
Lophopanopeus bellus		2	1		1
Pagurus spp.	3	3	3	3	3
Upogebia pugettensis	1	2	2	2	1

	SANDPT	NORWEG	ALAVA	KAYOST	CHILEAN	
Petrolisthes cinctipes	3	3	2		1	
Petrolisthes eriomerus		2	2		1	
Pachycheles rudis		1				
majid crabs (spider + decorator spp.)	1	1	1	1	1	
Shrimp, incl. *Sergia tenuiremis* + *Heptacarpus sitchensis* + *littoralis pugettensis* + *Hippolyte clarki* + *Crangon nigricauda*		1	2	2	1	1
TANAIDS: *Leptochelia savignyi*			2			
INSECTS: *Cercyon fimbriata*			1			
BARNACLES						
Semibalanus cariosus	1					
Balanus glandula	2	2	1	1	1	
Chthamalus dalli	1	2	1	1	1	
Pollicipes polymerus		1				
Balanus crenatus		1				
PH. BRYOZOA						
encrusting spp., incl. *Tricellaria* spp. + *Eurystomella* spp.	2	2	1		1	
Dendrobeania sp.		1				1
Alcyonidium polyoum	1					
PH. ECHINODERMATA: URCHINS						
Strongylocentrotus droebachiensis	1					
SEA CUCUMBERS						
Leptosynapta clarki		2	2	2		
Paracaudina chilensis			1			
SEASTARS						
Pisaster ochraceus	1	1				
Leptasterias hexactis	2	2	1		1	
Pynopodia helianthoides		1				
Henricia leviuscula	1	1	1			
BRITTLE STARS						
Amphipholis squamata		3	3			
Amphiodia periercta			3			
Amphiodia occidentalis	2	2		3		
Ophiopholis aculeata					2	
Amphioplus sp.					2	

	SANDPT	NORWEG	ALAVA	KAYOST	CHILEAN
PH. UROCHORDATA: TUNICATES					
Perophora annectens			1		
Metandrocarpa sp.		1			
Clavelina huntsmani			3		
Aplidium spp.	1				
Didemnum sp.			1		
Distaplia sp.			1		
thin tan encrusting ascid.		1			
PH. HEMICHORDATA					
(?)*Glossobalanus* sp.			1		
VERTEBRATES: FISHES					
Gobies: *Gobiesox meandricus*	1	1			
Blennies: *Pholis ornata* + *Xiphister mucosis* + *Anoplarchus insignis*	2	2	2		1
Cottids: *Oligocottus* spp. + *Artedius lateralis*	3	3	3	2	2

*Spirorbids found include:
Spirorbis bifurcatus, *Neodexiospira pseudocorrugata*, *Bushiella abnormis*, *Paradexiospira vitrea*, and *Circeis armoricana*.

APPENDIX D. SPECIES FOUND IN OR ADJACENT TO SAND TRANSECTS. **Sites are described in Tables 1 and 22. "KAY" = a short, coarse-sand transect done in the high-mid intertidal, near the Kayostla cobble transect. Most amphipods from all sites were identified by Dr. Craig Staude.**

	KAL	RUBY	2NDB	CEDAR	KAY	SANDPT	OCE
AMPHIPODS							
Fam. Haustoriidae							
Unidentified *Eohaustorius*						**2**	
Eohaustorius brevicuspis	**3**		**1**				
Eohaustorius sawyeri	**2**	**2**			**2**		**3**
Eohaustorius washingtonianus	**2**	**2**	**2**	**3**			
Fam. Oedicerotidae							
Monoculodes sp.		**1**					
Fam. Phoxocephalidae							
Grandiphoxus grandis	**2**		**2**	**2**			
Foxiphalus major		**1**					
***Mandibulophoxus* sp.1**		**1**					
Mandibulophoxus gilesi			**2**				
Rhepoxynius sp.	**1**						
Fam. Talitridae: Beachhoppers							
Megalorchestia californiana						**1**	
Megalorchestia columbiana	**2**				**2**	**1**	**2**
Megalorchestia pugettensis	**2**			**3**	**2**		
Traskorchestia georgiana						**3**	
Traskorchestia traskiana	**2**	**2**					
Fam. Ampithoidae							
***Ampithoe simulans*?**					**1**		
Fam. Hyaleidae							
Hyale frequens					**1**		
Hyale plumulosa				**1**			
***Parallorchestes* sp.**					**1**		
Fam. Ischyroceridae							
Ischyrocerus* cf. *anguipes					**1**		
***Jassa* spp.**				**1**			
Fam. Pontogeneiidae							
Paramoera serrata	**1**						
Pontogeneia* cf. *ivanovi					**1**		
Fam. Dogielinotidae							
Proboscinotus loquax	**3**					**3**	**1**

	KAL	RUBY	2NDB	CEDAR	KAY	SANDPT	OCE
ISOPODA							
Suborder Flabellifera							
Excirolana spp.	3		3	2	2	3	2
Suborder Oniscoidea							
Alloniscus perconvexus							1
Littorophiloscia richardsonae							1
Porcellio scaber	1						
MYSID							
Archaeomysis grebnitzkii	2		1	1		1	
BIVALVE							
Siliqua patula	3		1				3
GASTROPODA							
Olivella biplicata						3	3
POLYCHAETES							
Fam. Phyllodocidae							
Eteone tuberculata	2		2	1			
Fam. Nephtyidae							
Nephtys brachycephala	2			1			
Nephtys californiensis				1			1
Nephtys ferruginea?		1					1
Nephtys longosetosa	2	1	1				2
Fam. Opheliidae							
Euzonus mucronatus	3				3	2	
Fam. Orbiniidae							
Leitoscoloplos pugettensis		2					
Fam. Lumbrineridae							
Lumbrineris luti				2		1	
Fam. Spionidae							
Unidentified spionids				2			2
Pygospio elegans							2
Scolelepis squamata		2					
Scolelepis foliosa		3	1				3
NEMERTEANS							
Unidentified nemert.		2	2			2	1
Amphiporus tigrinus	1						
Cerebratulus ?californiensis	1						
Tubulanus pellucidus	2	1					
Zygonemertes virescens	1						

END

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